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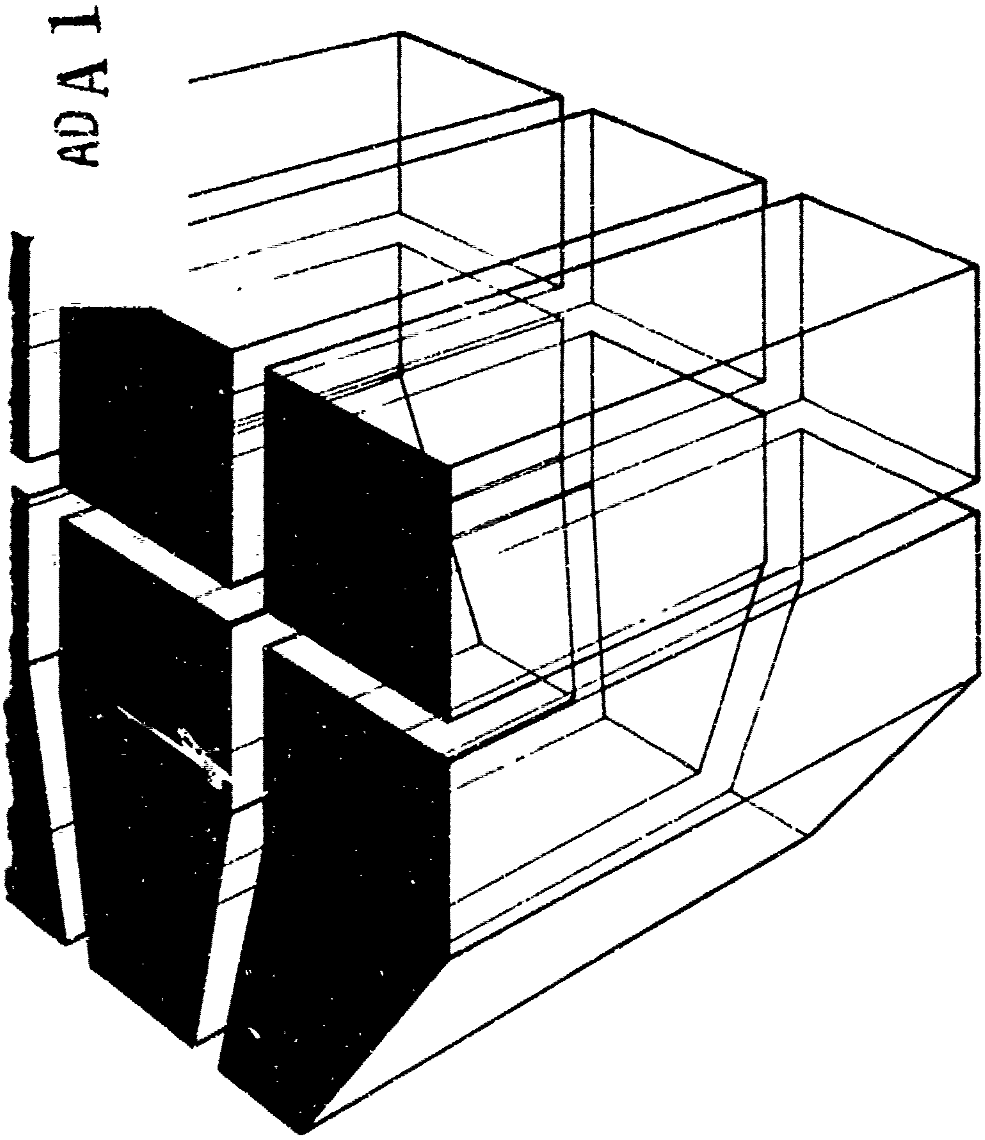
PROTECTIVE COATINGS FOR ALUMINUM TORPEDOES



by
S. A. Johnston

CERL

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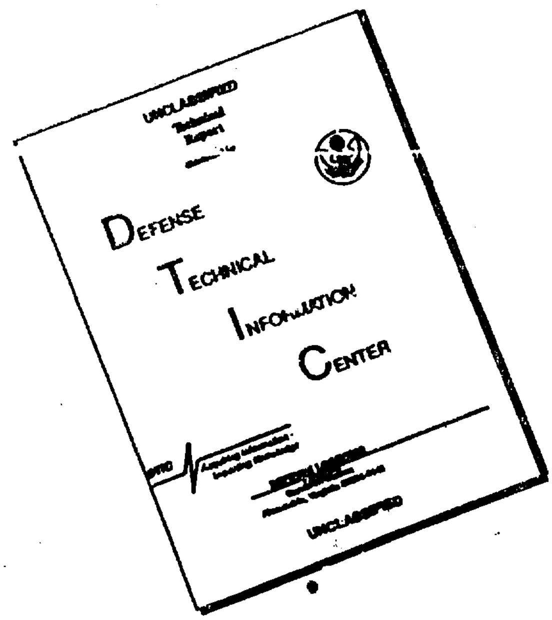

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The U.S. Navy is now using a proprietary polyurethane coating on its aluminum torpedoes. Although this coating has good resistance to rough handling and corrosive environments, there are two drawbacks:

1. Some people are highly allergic to the isocyanate materials in urethane coatings; there is concern that the Occupational Safety and Health Administration (OSHA) may restrict the use and availability of these coatings.

(Continued on next page)

BLOCK 20 (Continued)

2. The polyurethane now used is a proprietary material. If it became unavailable for any reason, it would be difficult to select an alternative coating system because there is little experience with other systems in this environment.

To address these problems, the Navy asked the U.S. Army Construction Engineering Research Laboratory to evaluate alternative coatings for aluminum.

The objectives of this study were to select and evaluate aluminum coatings and coating systems for their resistance to mechanical handling, and for their capability to protect aluminum from corrosion in seawater and Otto fuel, the torpedo propellant.

Of the 10 coating systems tested for this study, two were found to be suitable for use on torpedo exteriors:

1. The epoxy-polyamide coating MIL-P-24441 has excellent corrosion resistant properties. Formula 158 and Formula 152 are the primer and topcoat within the specification which are best suited for use on aluminum substrates. The MIL-P-24441 system has excellent adhesion. The impact resistance of this coating is best if the topcoat is applied at no more than 5 mils dry film thickness. The MIL-P-24441 system had the best overall performance of the 10 candidate coatings for torpedo exteriors.

2. The Ameron vinyl system (Amercoat 86 primer and Amercoat 99HS topcoat) provides a high degree of corrosion protection, has good impact resistance and adhesion, and (because it is a solution vinyl) should be easily repaired when the original coating is damaged. A 15-mil thick coat of this vinyl provides much greater protection against damage by impact than does a 10- or 5-mil coat. Adequate drying time must be allowed before putting this coating system into immersion, or premature loss of adhesion may result. The flexibility, repairability, and good performance of this coating make it a good second choice of the 10 candidate coatings for torpedo exteriors.

To coat the lining of a torpedo's internal fuel tank, the MIL-C-4556 system had the best overall performance when applied over the dichromate sealed, hardcoat anodized 7075 series aluminum. When undamaged, this coating is highly resistant to deterioration in Otto fuel, seawater, or a mixture of the two. When the coating is physically damaged, it does not break away from the damaged area, but remains intact even if corrosion has undercut the coating.

FOREWORD

This study was done by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL) for the Naval Underwater Systems Center under MIPR No. N660481 MP10005. The Navy technical monitor was Mr. H. Pearl, Code 36622. The Navy funding was provided by Work Unit Number (WUN) 106, whose Principal Investigators are Mr. K. J. Haydon, NAVSEA-PMS-402 F12, and Mr. J. R. Quartarone, NUSC 36112.

The assistance of Mr. R. G. Lampo in the preliminary work on this project is acknowledged.

Dr. R. Quattrone is Chief of EM. COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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PROTECTIVE COATINGS FOR ALUMINUM TORPEDOES

1 INTRODUCTION

Background

When aluminum alloys are selected, their strength is often considered first, while the environment to which they will be exposed is a secondary consideration. In seawater, for example, the 6000 series alloys have good corrosion resistance while the 7000 series alloys do not; however, the 7000 series is often used because it is stronger.

Since the Navy's MK48 torpedoes are typically manufactured with 7000 series aluminum, the exteriors must be coated to protect against corrosion caused by seawater. The internal surface of the aluminum fuel tank must also be coated. This coating must be resistant to the corrosive properties of Otto fuel (the torpedo propellant) and of any mixture of Otto fuel and seawater. Although gouging and abrasion are not a problem inside the fuel tank, the coating must be highly adherent and nonflaking because any loose particles could enter the propulsion mechanism and cause a malfunction.

The Navy is now using a proprietary elastomeric polyurethane coating on its aluminum torpedoes. Although this coating has good resistance to rough handling and corrosive environments, there are two drawbacks:

1. Some people are highly allergic to the isocyanate materials in urethane coatings; there is concern that the Occupational Safety and Health Administration (OSHA) may restrict the use and availability of these coatings.

2. The polyurethane now used is a proprietary material. If it became unavailable for any reason, it would be difficult to select an alternative coating system because there is little experience with other systems in this environment.

To address these problems, the Navy asked the U.S. Army Construction Engineering Research Laboratory (CERL) to evaluate alternative coatings for aluminum.

Objectives

The objectives of this study were to select and evaluate a very limited number of coatings and coating systems for aluminum that are resistant to mechanical handling and seawater corrosion (Task I), and to protect aluminum from corrosion in seawater and Otto fuel (Task II). Emphasis was placed on nonpolyurethane coatings. The candidate coatings were to be selected based on major differences in polymer composition and physical properties. The results are to be used for direction in developing more effective organic coatings.

Approach

Task I: Nine potentially suitable candidate coating systems for torpedo exteriors were selected for this study. These coatings were tested, evaluated, and ranked in order of effectiveness. Some proprietary coatings were evaluated, but priority in selection was given to applicable Federal or military specification materials. No specific repairability tests were included, but priority was given to organic coatings that might be easily repaired after they were damaged. To help ensure that the same paint is obtained in the future, physical and chemical tests were performed to characterize and identify the major constituents and their concentrations. Additional characterization of constituents was obtained from pertinent vendor data and material safety sheets. The testing and evaluation of the performance of the coatings examined mechanical strength; impact, adhesion, and corrosion resistance; as well as electrical measurements of the impedance, resistance, and capacitance of the paint systems on anodized or chromate conversion pretreated 7075-T6 aluminum panels before, during, and after a 90-day immersion in aerated synthetic seawater. The effect of coating thickness and/or the nature of the substrate pretreatments was determined. The presently used elastomeric polyurethane coatings and other types of polyurethanes were tested to compare their performance. The corrosion performance of unpainted specimens was also observed.

Task II: The candidate coatings for the torpedo fuel tanks were selected, tested, and evaluated. These coatings were ranked for adherence, nonflaking, and corrosion protection for anodized or chromate conversion pretreated 7075-T6 aluminum alloy specimens in seawater, Otto fuel, or a mixture of 50 percent seawater and 50 percent Otto fuel. Tests conducted include impact, adhesion, immersion, and electrical evaluations similar to those for Task I. The corrosion performance of unpainted specimens immersed in the pertinent liquids was determined.

2 MATERIAL SELECTION AND PREPARATION OF TEST SPECIMENS

Selection of the Coatings

To select the coatings to be evaluated, CERL searched the Federal and military paint specifications to find those appropriate for the given exposures. Epoxy primer, military specification MIL-P-23377, was used for all tested coatings (both specification and proprietary), unless a different primer was needed for a given system. Based on this search, CERL found that it would be worthwhile to evaluate the following coatings for Task I:

1. Nonurethane:

   — Epoxy-polyamide

   — Epoxy-polyamine

   — "Flexible" epoxy

   — 100 percent solids epoxy

   — Vinyl.

2. Urethane:

   — Currently used elastomeric system

   — Currently used elastomeric topcoat over MIL-P-23377 primer

   — Nonelastomeric urethane system

   — High-build urethane system.

For Task II, it was decided to select coatings designed for fuel tank linings. All coatings chosen were epoxy materials.

The coatings selected for evaluation are discussed below. The basis for selection and the source of sample materials are given.

Task I

Nonurethane Coatings. Six different coatings were selected for this part of the study.

1. Epoxy-polyamide meeting MIL-P-24441. It was known that this specification material has excellent seawater and chemical resistance. However, CERL had to find out whether this coating has the necessary flexibility, gouge, and impact resistance. This specification is subdivided into various formulas for different topcoats and primers. Formula 158 primer was selected since it is specifically formulated to be used over aluminum and with the MIL-P-24441 topcoats.

Samples of the Formula 158 primer (yellow) were obtained from:

Matcote Company
P.O. Box 10762
Houston, TX 77018

Sampl.. of the Formula 152 topcoat (white) were obtained from:

Mobil Chemical Company
901 North Greenwood
Kankakee, IL 60901

2. Epoxy coating system meeting MIL-C-4556. This coating specification is really a coating system. That is, the specification covers both an epoxy-polyamide primer and an epoxy-polyamide topcoat. This system is meant for fuel tanks, and therefore has excellent chemical resistance and adhesion. Several paint manufacturers recomme... this specification for both the exterior of torpedoes and the interior of the fuel tanks. This coating was evaluated for both Task I and Task II. If the performance were acceptable in both exposures, only one coating system would need to be specified for the torpedoes.

The sample for this evaluation was obtained from:

Plas Chem Coatings
6300 Bartmer Industrial Drive
St. Louis, MO 63130

The primer tested was orange in color, and the topcoat was white.

3. "Flexible" epoxy meeting MIL-C-22750. As with most epoxy-polyamide coatings, this was expected to have good seawater and chemical resistance. The advantage of this material is that it can be made more flexible than MIL-P-24441 epoxy. Chemrex Specialty Coatings Company, El Paso, TX, prepared a sample in its laboratory. The sample was formulated to provide good flexibility and to meet Federal Standard 595 color #14062 (dark green).

4. A 100 percent solids epoxy coating. Steelcote Manufacturing Company, Saint Louis, MO, claims to have an epoxy coating that has: (1) the needed resistance to seawater corrosion, (2) an inherent flexibility and toughness, and (3) no volatile solvents. CERL tested a sample made in Steelcote's laboratory and pigmented to meet color #14062.

5. The MIL-P-23377 epoxy primer. This was tested at a thickness of 5 mils and without a topcoat. The coating was obtained from:

Deft, Inc.
17451 Von Karman Avenue
Irvine, CA 92714

This primer is yellow.

6. Vinyl coating system. Solution vinyl coatings are typically tough and flexible, and have reasonably good chemical resistance. One advantage is that they can be applied over an old vinyl coating with no intercoat adhesion problems providing the old surface is clean.

A vinyl coating system manufactured by Ameron, 201 North Berry Street, Brea, CA 92621, was selected for this study. The system includes a synthetic resin inhibitive primer, Amercoat 86, and a topcoat, Amercoat 99HS. These materials are standard off-the-shelf products. The topcoat is Ameron's color, medium green, which is lighter than the #14062 color. The primer color is red oxide.

Urethane Coatings. Four different coating systems were evaluated.

1. Currently used urethane system. This consists of a vinyl butyral phosphoric acid wash-primer first coat (Lord, Hughson identification #TS 3236-26, yellow) and an elastomeric topcoat made from an aliphatic polyisocyanate and a butyl ketoxime blocked aromatic polymine (Lord, Hughson #TS 3236-23A/B, revision #1, color #14062) manufactured by Lord Corporation, Chemical Products Group, Erie, Pennsylvania 16514.

2. Currently used urethane system topcoat manufactured by Lord Corp. over MIL-P-23377 primer obtained from Deft, Inc.

3. Nonelastomeric aliphatic urethane coating meeting military specification MIL-P-83286. This coating is a topcoat material only; it was applied over MIL-P-23377 primer. A single, small sample of this coating in color #14062 could not be obtained in an acceptable time at a reasonable cost. However, the manufacturer, Deft, Inc., maintained t[illegible] making the correct color should not be hard, and that the pigmentation [illegible]fference should not be a great factor in its performance properties. A sampl[illegible] a white coating pigmented with titanium dioxide, conforming to MIL-P-8[illegible] [illegible]as received from Deft, Inc.

4. High-build elastomeric polyurethane. A yellow topcoat, Irathane 155, was applied over the MIL-P-23377 yellow primer. The topcoat was obtained from Irathane Systems, Inc., Hibbing, MN.

Task II

Three coatings were selected for this portion of the study.

1. Flexible epoxy-polyamide meeting MIL-C-22750. In the technical manual on Otto Fuel II, an epoxy coating meeting MIL-P-22808 is listed as an acceptable tank lining.[1] However, MIL-P-22808 has been cancelled and replaced by MIL-C-22750. MIL-C-22750 was also evaluated as a coating for the torpedo exteriors. Chemrex supplied a sample for testing. The topcoat meets color #14062.

2. Epoxy coating meeting military specification MIL-C-4556. This coating might be expected to have slightly better chemical resistance than the

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[1] Otto Fuel II: Safety, Storage, and Handling, NAVSEA OP 3368 Fifth Revision (Naval Sea Systems Command, 15 January 1973, Change 1, 15 May 1975).

MIL-C-22750 coating. MIL-C-4556 is a primer and a topcoat system. This coating also was evaluated for torpedo exteriors. Plas Chem supplied samples of the orange primer and a white topcoat formulation.

3. Amine-cured epoxy coating meeting Boeing Aircraft specification #BMS-10-11K. It was thought worthwhile to include in this study an industry specification material used for lining tanks which may contain material similar to the Otto fuel. The Boeing specification material is a readily available, conventionally pigmented coating. It is self-priming and need not be topcoated as long as the material is not exposed to sunlight. This coating was obtained as an off-the-shelf product from Deft, Inc. The coating is light green in color.

Aluminum Test Specimens

All aluminum test specimens were 3 in. by 6 in. by 0.125 in. aluminum alloy 7075-T6. The panels were divided among three groups. Throughout this report, these three pretreatments will be called substrates a, b, and c:

substrate a — 7075-T6 with a 2 (± 0.5)-mil-thick Type III, class 1, dichromate sealed, hardcoat anodizing in accordance with MIL-A-8625C, 15 January 1968 and amendment 1, 13 March 1969.

substrate b — 7075-T6 with a 2 (± 0.5)-mil-thick Type III, class 1, unsealed, hardcoat anodizing in accordance with MIL-A-8625C, 15 January 1968 and amendment 1, 13 March 1969.

substrate c — 7075-T6 with a chromate conversion coating, class 1A, in accordance with MIL-C-5541, 30 June 1970 and amendment 2, 30 November 1972.

The test panels were made from the same batch of stock material. All edges were deburred and rounded. A single 1/4-in. hole was drilled in each specimen centered on the 3-in. side and 1/4 in. from the edge. The panels were degreased, cleaned, and blasted on all sides and edges with silica sand to a white metal finish and a mean surface profile of approximately 1 mil before treatment. The specimens were supplied by:

The Metaspec Company
P.O. Box 27707
San Antonio, TX 78227

Application of the Coatings: Techniques and Observations

All coatings in this study were applied by conventional suction-cup air spray equipment, except as noted in Table 1.

To evaluate the effect of film thickness on coating performance, almost all the nonpolyurethane coatings for Task I were applied at topcoat dry film thicknesses of 5, 10, and 15 mils. The urethane coatings were applied at a topcoat dry film thickness of 5 mils — except for the high-build urethane system, which was applied at 15 mils. The urethanes were applied over substrates a, b, and c. Successful preliminary results on the MIL-P-24441 epoxy

Table 1

Application of the Coatings

Coating	Thinner	Equipment	Pot Life	Problems
MIL-P-24441 topcoat and primer	None	Conventional	5 hours	None
MIL-C-4556 topcoat and primer	None	Conventional	6 hours	None
MIL-P-23377 primer	None	Conventional	8 hours	Does not dry to a smooth finish over anodizing
MIL-C-22750	MIL-T-81772	Conventional	6 hours	Air bubbles if more than a very thin coat is applied
100% solids epoxy	None	Conventional airspray fitted with a pressure pot	1-1/2 to 2 hours	Sagging, dripping
Amercoat 86 primer	Amercoat 6	Conventional airspray fitted with a pressure pot and a fine tip	Unlimited	Cobwebs
Amercoat 99HS topcoat	Amercoat 9	Conventional airspray fitted with a pressure pot	Unlimited	Pinholes if not thinned sufficiently
Hughson wash primer	None	Conventional	8 hours	None
Hughson polyurethane topcoat	None	Conventional	2 hours	None
MIL-C-83286	None	Conventional	6 hours	Air bubbles if more than a thin coat is applied
Irathane 155	None	Conventional	3 hours	None
BMS-10-11K	None	Conventional	8 hours	Must be applied in multiple thin coats to avoid surface tension problems

system and the Ameron vinyl system suggested that these coatings be evaluated over all three substrates.* Other coatings in Task I were evaluated on substrate a only.

Task II coatings were applied at the thickness suggested by the manufacturer or by the military specification. These coatings were applied to all three substrates.

The techniques used to apply each coating are discussed below. This information is summarized in Table 1.

MIL-P-24441: Both the primer and the topcoat were easily mixed and applied without thinning. Each coat was allowed to dry overnight before recoating. Each coat dried to a thickness of about 3 mils.

MIL-C-4556: Both the primer and the finish coat sprayed easily with conventional suction-cup spray. Thinning was not necessary. The primer was applied at approximately 2 mils dry film thickness. Each coat of the topcoat was about 5 mils dry film thickness. Each coat was allowed to dry overnight before recoating. The system became very hard and brittle as it cured.

MIL-P-23377: This primer was used with several different topcoats. It was applied at a thickness of 1 mil with no thinning. Some difficulty was encountered in applying the primer to the anodized aluminum panels, both with and without the dichromate sealing. These surfaces are somewhat porous, and the solvents in the primer were absorbed into the surface as the coating was applied. The primer dried with a sandy, rough surface when applied at a 1-mil thickness over anodizing. Applying a somewhat heavier coat prevented much roughness, but the coating still did not have the smooth surface that normally would be expected. There was no problem in applying this primer over the nonanodized chromate conversion coated panels.

MIL-C-22750: This coating was very difficult to spray. When more than a mist coat was applied, air bubbles up to 1/8 in. in diameter appeared on the surface about a minute after spraying. This happened whether the coating was thinned or unthinned, or was applied on smooth metal, sandblasted metal, or over the MIL-P-23377 primer. Acceptable results were obtained only with very careful work. The coating was thinned to 18 seconds on a #4 Ford cup with the MIL-T-81772 thinner recommended in MIL-C-22750. The first coat was applied as a very thin mist and allowed to dry for 1 hour before recoating. This coating was chosen for testing in Tasks I and II. Task I required coating thicknesses of 5, 10, and 15 mils. Since the coating could only be applied in coats of less than 1 mil, it was difficult and time consuming to obtain the necessary film build. The Task II specimens were coated according to MIL-C-22750 directions with a mist coat and one more coat. The total thickness of the topcoat was 0.9 to 1.2 mils.

The 100 percent solids epoxy coating: This coating was applied using conventional spray equipment fitted with a pressure pot. A pressure of about 15 psi was applied to the pot. To apply a 5-mil coat, the coating was sprayed to give a "spattered" coat which did not cover the entire surface. Within a

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* Both coatings were rated highly on physical tests performed before immersion.

few seconds this coat flowed together smoothly and uniformly. The coating has some tendency to sag and drip, even at 5 mils. It was not possible to spray the panels at a thickness of less than 5 mils. Each coat was allowed to cure overnight before recoating.

Ameron 86 and Ameron 99HS: The primer, Amercoat 86, was thinned to 25 seconds on the #2 Zahn cup with Amercoat 6 thinner. It was difficult to get good atomization of this paint with conventional spray equipment. The best results were obtained using the pressure pot and a fine atomizing tip on the spray gun. Two fast passes of the spray gun gave an even coat about 1.5 mils thick. The first pass was allowed to dry a few minutes before the second coat was sprayed on. The primer was messy to apply; during spraying, semidry paint particles and cobwebs filled the air. The topcoat was thinned to 90 seconds on the #2 Zahn cup; about one part paint was mixed with one part thinner. Without this much thinning, the coating had many pinholes. Each coat dried to a thickness of about 1 mil. The topcoat dried rather quickly, so several coats could be applied with only a few minutes' drying time between coats. The topcoat dried to a very dull finish.

Hughson TS 3236-26 and TS 3236-23: Both the wash primer and the topcoat were easy to apply; mixing and spraying presented no particular problems. The wash primer was applied in one thin coat and dried quickly. The topcoat was easily applied over both the wash primer and the MIL-P-23377 epoxy primer. A film build of 5 mils was achieved by applying six coats with a few minutes' drying time between each coat.

MIL-C-83286: No thinning was necessary when applying this polyurethane coating. The first coat had to be a very thin mist coat, otherwise, bubbles formed in the coating. The mist coat was allowed to dry for about 1 hour before recoating. A third coat was applied after overnight drying to give a 5-mil dry film thickness. Many of the panels had pinholes, but these flaws did not appear to go through all coats. There were no pinholes in the MIL-P-23377 primer.

Irathane 155: There were no particular problems with either mixing or spraying. No thinning was required. A dry film thickness of 4 to 5 mils was applied for each coat.

BMS-10-11K: This coating was easy to apply with no thinning; as recommended, no primer was used. Two thin coats were applied to give a dry film thickness of about 1 mil. When one heavier coat was applied, surface tension gave the coating an alligator-skin appearance.

Preparation of the Panels for Immersion

Thickness Measurements

The thickness of the coating on each panel was determined by measuring the total thickness of the coated panel, then subtracting the thickness of the uncoated panel, and dividing by two to get the coating thickness on each side. The measurements were made using a gauge calibrated in mils. The gauge was bolted to a stationary support. The movable dial was rotated to read zero thickness for an uncoated panel. The dial was recalibrated for each substrate

(anodized sealed, unsealed, and chromate conversion coated). This method of measuring total coating thickness assumes that each uncoated panel is the same thickness, and that the film on one side of the panel is the same thickness as that on the other side. The thicknesses of several uncoated panels were measured; the differences between them were minimal. Three measurements were recorded for each panel, about 1 in. from the long edge at the top, middle, and bottom of the panel. The number of panels per test and the [illegible] coating thickness measurement values are included in Table 2. It was difficult to apply the coatings at the exact film thicknesses desired. The [illegible] in coating thicknesses were normally less than 1.5 to 2.0 mils. Table 2 also includes the number of test specimens for each coating system, thickness, and substrate.

Preparation of Panels for Electrical Measurements

To attach electrical leads to a specimen, part of the coating and anodizing was removed at the top of each panel. A steel template with a 1/2-in.-diameter hole at the top was placed over the panel, and the coating was removed by sandblasting. This technique removed the coating from a small area without damaging the rest of the panel. A 1/8-in. hole was drilled in the center of the clean area, and a solderless terminal was riveted in place (Figure 1). Before it was attached, the terminal was dipped in a conductive silver paint. The bare metal areas were then covered with silicone sealant to protect the connection from the corrosive seawater and Otto fuel.

Galvanically Coupled Panels

Each of the coated specimens in this phase of the testing was galvanically coupled to two brass panels of the same size as the specimen. Leads were soldered to the brass panels; a longer lead coupled one brass panel to the coated panel. Each coated panel was sandwiched between the two brass panels and bolted together using nylon nuts, bolts, and washers (Figure 2). Four washers were inserted between each panel to provide 1/8-in. spacing. The leads from the brass and coated panel were cut to 6 in.; the ends were stripped, twisted together, and soldered. The assembled panels were suspended in the tanks with the coupled ends of the wires well above the surface of the immersion liquid. These panels did not require electrical measurements and did not have to be disassembled until the testing was completed. The length of the wires allowed the panels to be twisted apart enough to observe the condition and appearance of the coating during immersion.

Scored Specimens

Some of the coated specimens were scored with a diamond-tipped cutting tool. Two parallel 3-1/2-in.-long scribe lines were cut 1 in. apart on each face of the panel (Figure 3). The top of each scribe line was 1 in. from the top edge of the panel. On each panel, the left-hand scribe line was cut through to bare metal; the right-hand scribe line was cut through all layers of the coating to the anodizing.

Table 2

Mean Coating Thicknesses

Coating	Substrate	Intended Thickness (mils)	# of Panels	Mean Thickness (mils)	Standard Deviation
Task I: Nonurethanes					
MIL-P-24441	a	6	16	6.4	0.75
over	a	11	16	10.9	1.01
MIL-P-24441	a	16	16	14.0	1.29
	b	6	16	5.7	0.88
	b	11	16	10.4	1.18
	b	16	16	14.5	1.25
	c	6	16	5.0	0.56
	c	11	16	9.5	0.83
	c	16	16	13.1	2.04
MIL-C-4556	a	6	16	6.0	0.70
over	a	11	16	10.5	1.07
MIL-C-4556	a	15	16	10.6	1.19
MIL-C-22750	a	6	16	4.2	0.57
over	a	11	16	8.4	0.74
MIL-P-23377	a	16	16	12.4	0.90
100% Solids	a	6	16	5.7	0.93
over	a	11	16	5.5	0.65
MIL-P-23377	a	16	16	16.3	1.64
MIL-P-23377	a	6	16	6.6	0.59
	b	6	16	5.4	0.60
	c	6	16	5.1	0.65
Amercoat 99HS	a	6	16	5.4	0.82
over	a	11	16	9.7	0.69
Amercoat 86	a	16	16	15.6	1.13
	b	6	16	7.4	0.96
	b	11	16	12.5	0.95
	b	16	16	18.0	1.07
	c	6	16	8.3	0.60
	c	11	16	12.7	0.81
	c	16	16	21.9	1.75
Task I: Urethanes					
Hughson	a	6	16	7.3	0.54
TS 3236-23	b	6	16	8.2	0.64
over	c	6	16	8.0	0.51
TS 3236-26					
Hughson	a	6	16	4.1	0.41
TS 3236-23	b	6	16	4.9	0.45
over	c	6	16	4.5	0.55
MIL-P-23377					
Irathane 155	a	16	16	13.7	2.58
over	b	16	16	18.4	2.17
MIL-P-23377	c	16	16	18.4	1.43

Table 2 (Cont'd)

Coating	Substrate	Intended Thickness (mils)	# of Panels	Mean Thickness (mils)	Standard Deviation
		Task II			
MIL-C-22750	a	2	26	2.2	0.58
over	b	2	26	3.4	0.51
MIL-P-23377	c	2	26	2.8	0.56
MIL-C-4556	a	9	26	8.6	1.36
over	b	9	26	8.6	1.54
MIL-C-4556	c	9	26	7.1	0.98
BMS-10-11K	a	1	26	1.2	0.50
	b	1	26	2.2	0.46
	c	1	26	2.0	0.61

Figure 1. Solderless terminal.

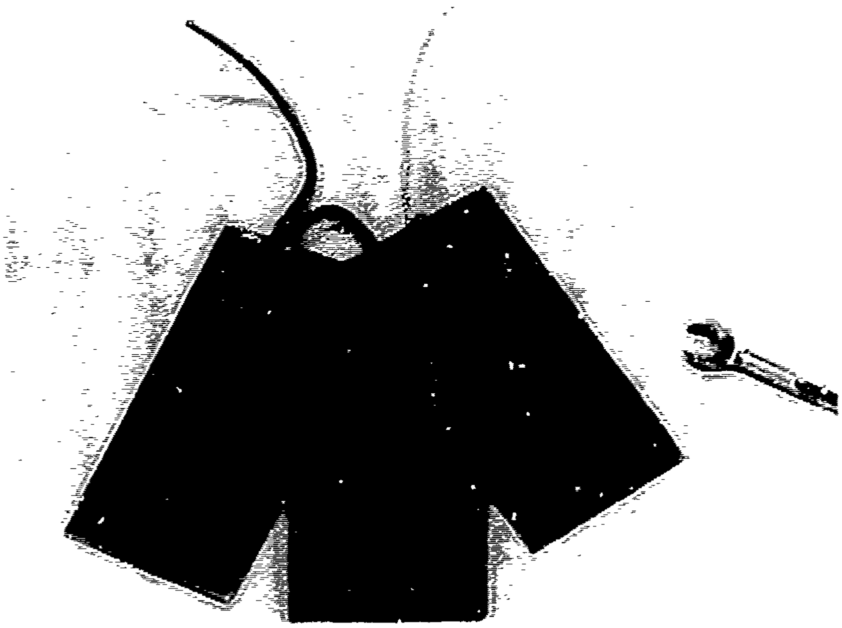

Figure 2. Assembly of galvanically coupled specimen.

Figure 3. Scribe lines.

Some of the coated specimens were impacted before immersion. This was done with a Gardner Heavy-Duty Variable Impact Tester. Four points in predetermined locations on each panel were impacted with forces of 5, 10, 20, and 40 in.-lb as shown in Figure 4. Since most coatings fail in the range of 5 to 40 in.-lb, each panel had at least one actual coating failure among the four points of impact. Figure 5 shows a specimen which corroded only at the point which was impacted with a force of 40 in.-lb. The specimen was galvanically coupled and immersed in seawater for 90 days.

Undamaged Specimens

Some of the specimens were not damaged prior to immersion. Figure 6 shows a specimen coated with MIL-P-24441 which did not visibly corrode during 90-day immersion in seawater. The specimen was galvanically coupled.

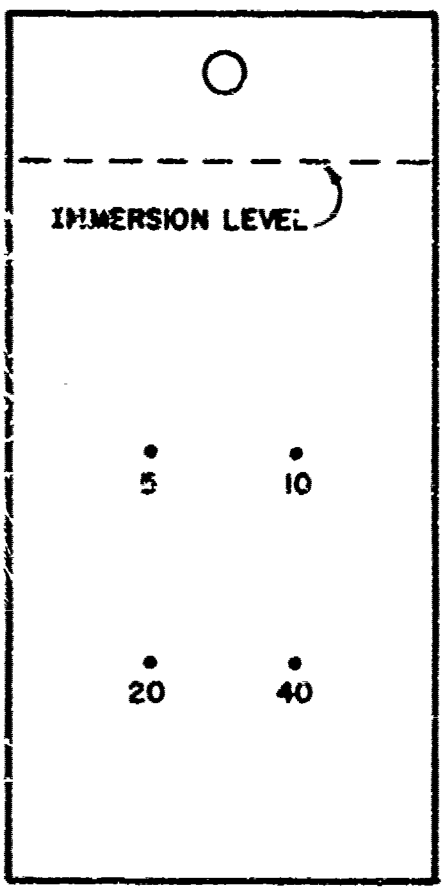

Figure 4. Location of pre-immersion points.

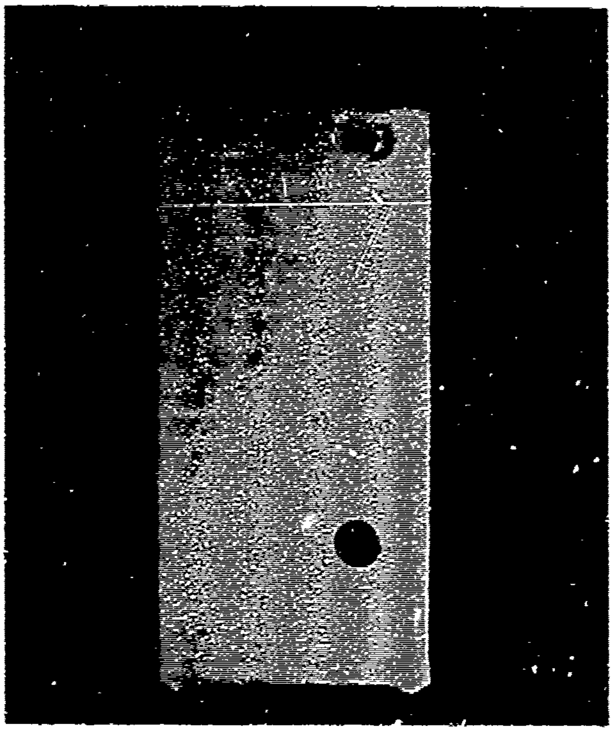

Figure 5. Specimen corroded at 40 in.-lb impact point.

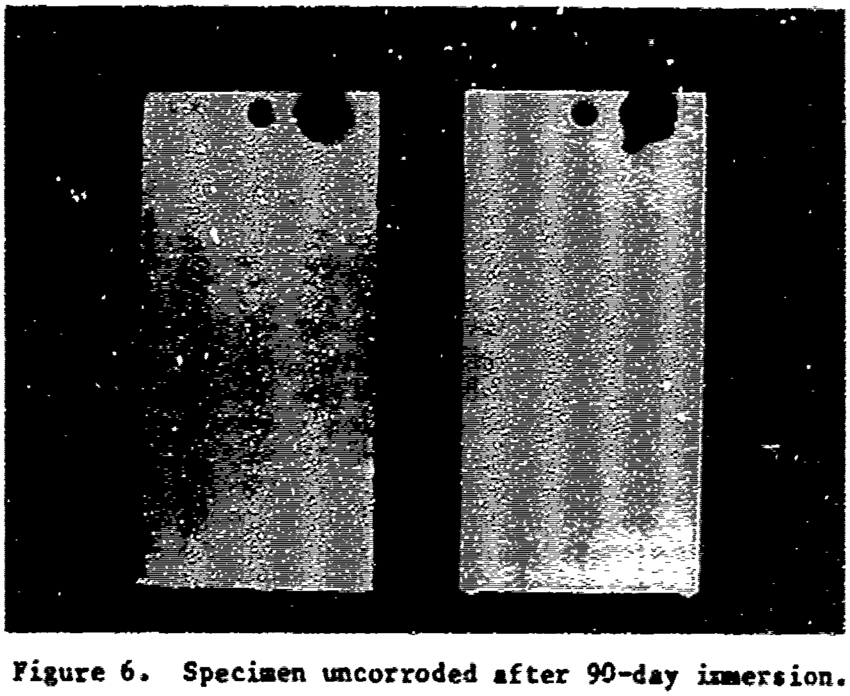

Figure 6. Specimen uncorroded after 90-day immersion.

3 TEST METHODS

More than 900 aluminum panels were coated and tested. Most of the specimens were immersed for 90 days in seawater, Otto fuel, or a mixture of the two. Some specimens were damaged before immersion by impact or by score lines cut into the coating surface. Some of the damaged and undamaged test specimens were galvanically coupled to 60/40 bronze during the immersion period to accelerate the corrosion processes. Electrical measurements of resistance, capacitance, and loss factor at 1 kHz were made on 250 panels weekly during the 90-day immersion period. After the immersion period, each panel was examined to evaluate its condition. The results of the electrical measurements were tabulated, and the resistance and capacitance were plotted versus time of immersion. These plots were not found to give valuable information about the deterioration of the coatings within the 90-day immersion period. The results were not used because the data indicated the immersion time was too short to provide useful information.

Four destructive physical tests were performed on the specimens after immersion and on those specimens that were not immersed:

1. Elcometer adhesion test

2. Scrape adhesion test

3. Impact at room temperature (23°C)

4. Impact at 4°C.

Characterization tests were performed on each coating to provide a basis for comparing any batches of that coating procured by the Navy or CERL in the future with the samples already evaluated by CERL. The pigment content, total solids, and nonvolatile vehicle content of each coating were measured, and infrared and gas chromatographic analyses were performed.

Physical Test Procedures

Elcometer Adhesion Test

Originally, the adhesion of the coatings was to be tested using a tape adhesion method. For this test, two parallel cuts, 1/8 in. apart, and a third line perpendicular to the other two are cut into the coating. A piece of masking tape is firmly placed over the score lines and then peeled back to remove the coating. However, this test was shown to be ineffective because it would not remove many coatings. Therefore, CERL substituted the Elcometer Adhesion Tester. The test method involved using an epoxy glue to cement circular aluminum dollies to the coated surface. The dollies were lightly sandblasted on the contact surface to ensure good adhesion of the glue. The paint surface was also slightly roughened with sandpaper. Weights were placed on the dollies while the glue was curing. All specimens were allowed to cure overnight. A 1-in. hole saw attached to an electric hand drill was used to cut through the coating around the dolly. The dolly could then be pulled from the specimen with the adhesion tester, and the force at which the dolly was

pulled from the specimen was read in units of pounds per square inch. On most specimens, the dolly pulled all or part of the paint system from the panel. However, on some of the strongest coatings, the epoxy glue broke before the paint system, and the paint was left intact. The adhesion tester had a range of 0 to 1000 psi; the glue typically broke at 700 to 900 psi. Thus, this test did not distinguish between the highly adherent coatings, but it did indicate coatings with poor adhesion. One drawback of this test method is that the solvents in the glue might affect the characteristics of the coating system. For most coatings in this study, solvents would not be expected to have much effect because two-component cured coatings usually are solvent-resistant; however, the solution vinyl coating by Ameron is not. Thus, the Elcometer adhesion test may give false low readings for this coating in particular. Figure 7 is a photo of the test equipment after a test was performed.

Scrape Adhesion Test

A scrape adhesion test was performed with a balanced-beam scrape adhesion tester in accordance with American Society for Testing and Materials (ASTM) D 2197-68, Method A.[2]

ASTM D 2197-68A does not clearly state when the test should end; successively larger loads are to be used until the coating is removed or until the maximum load of 10 kg has been added. It is unclear whether the endpoint is the removal of the entire coating system from the substrate, or the removal of a portion of the topcoat from the surface. For the purposes of this testing, removal of any part of the coating constituted failure. (If the endpoint were removal of the entire coating system, many of the coatings would have exceeded the 10-kg limit of the apparatus.) The load was determined only to the nearest 0.5 kg because tests at smaller weight increments were not reproducible. The equipment at the conclusion of a test is shown in Figure 8.

Impact Test

An impact test was performed in accordance with ASTM D 2794-69.[3] The test was performed at a room temperature of 25 ± 1°C, and again on specimens cooled to 4 ± 3°C for 1 hour. The test was done on a Gardner Heavy-Duty Variable Impact Tester. A specimen was set over a 0.640-in.-diameter hole in a die mounted on the base of the apparatus. A spherical tipped punch of 0.625-in. diameter was placed on the specimen. A 2-lb weight was raised to a desired height (up to 40 in.) in a graduated tube; this weight delivered a maximum force of 80 in.-lb. The equipment is shown in Figure 9.

According to the test method, cracking of the coating constitutes impact failure. However, since some of the coatings in this study are so elastic that they will not crack, the endpoint was chosen as any of the following types of failure: cracking on the impacted side, cracking on the reverse side, puncture of the topcoat, and debonding ("blistering") of the impact area.

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2 "Standard Test Methods for Adhesion of Organic Coatings," D 2197 (American Society for Testing and Materials [ASTM], 1968).

3 "Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)," D 2794 (ASTM, 1969).

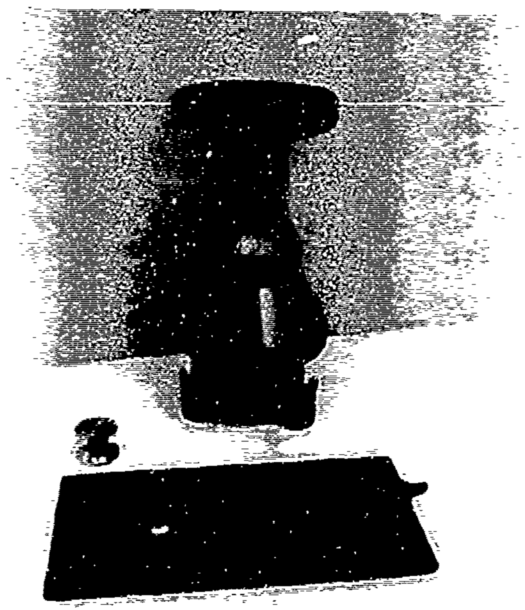


Figure 7. Elcometer adhesion tester.

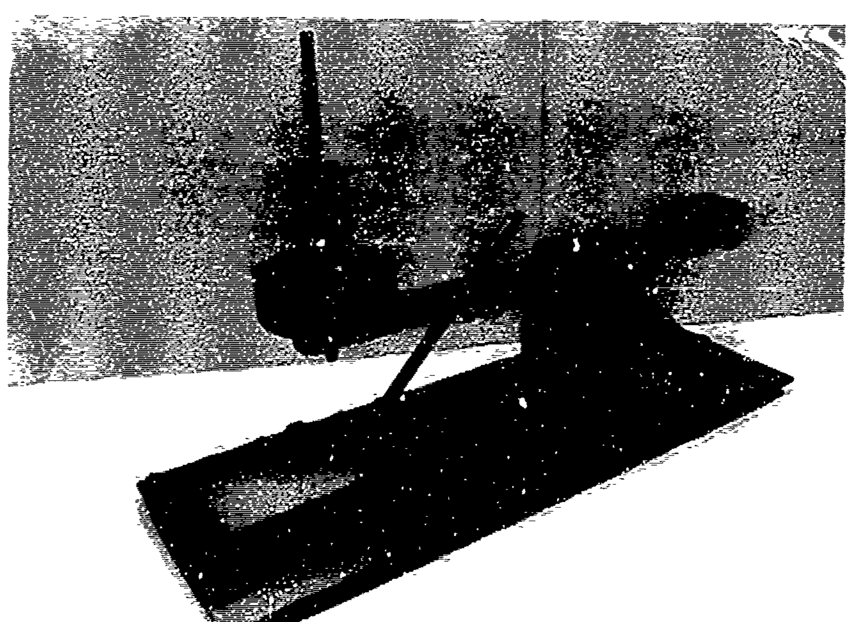


Figure 8. Scrape adhesion tester.

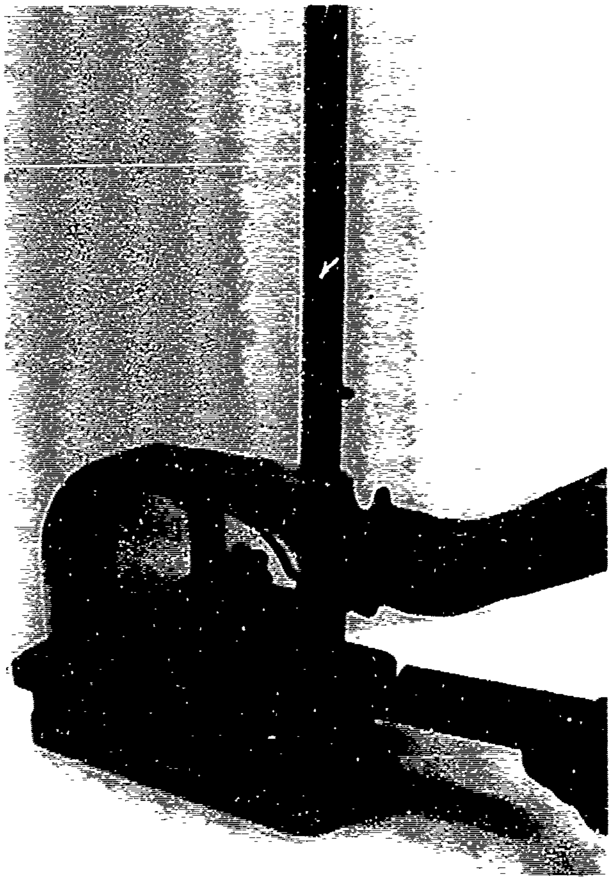
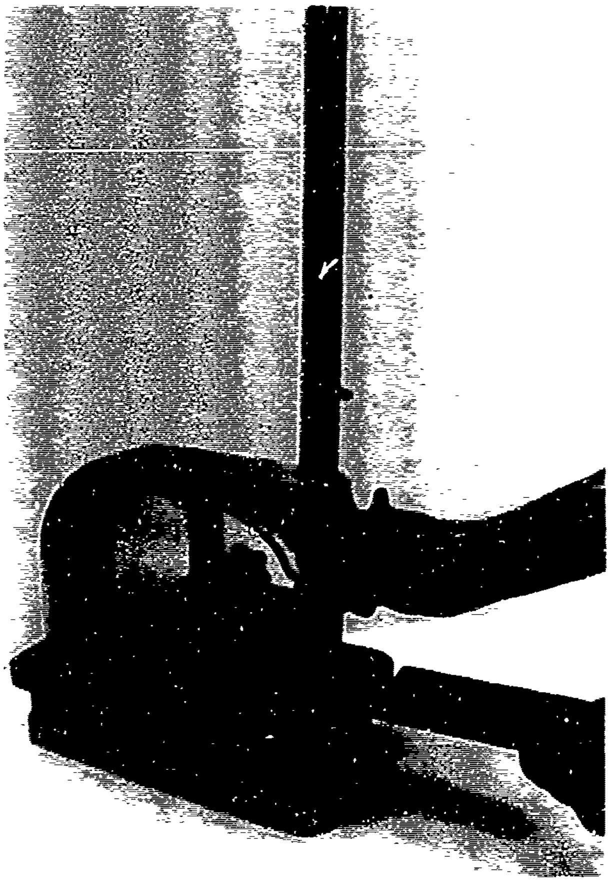


Figure 9. Gardner impact tester.

Electrical Measurements

It was originally thought that studying the resistance and capacitance properties of the coated aluminum specimens during immersion in seawater would yield valuable information about the deterioration of such specimens. The test method was based on previous studies of the electrical properties of polybutadiene coatings on steel. However, the test method did not give useful results for the coatings tested. A piece of stainless steel the same size and shape as the test specimen was used as a reference electrode. The distance between the reference electrode and the test specimen being measured was kept constant with three nylon screws set into the face of the reference electrode. Capacitance and impedance measurements were made with a General Radio Type 1600-A Impedance Bridge at a frequency of 1000 Hz. To prevent any errors caused by changes in the level of the immersion fluid, both the sample and the reference electrode were completely immersed. Measurements were made on each panel daily for the first 3 days, and then weekly for the rest of the 90-day testing period. It was expected that after a time the measured resistance between the specimen and electrode would drop sharply as the coating on the specimen deteriorated. The capacitance between the two would begin to rise at the same time. The data for this series of experiments did not show the



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expected trends. There were no significant increases or decreases in the values recorded during the 90-day testing period, even when there were visible areas of corrosion or coating deterioration on the specimens. Initial measurements of capacitance ranged from 0.2 to 5 microfarads. Initial measurements of resistance ranged from 10 to 250 ohms. The highest initial resistance values were for the MIL-P-4556 epoxy system. However, there did not appear to be a strong correlation between coating performance and electrical measurements. A 90-day immersion probably is not long enough to show significant changes in the electrical properties of the coated aluminum.

Characterization of the Coatings

To characterize each sample of paint tested for this study, the pigment content, total solids, and nonvolatile vehicle content of each coating component were measured (Table 3). An infrared spectrum (IR) and a gas chromatographic (GC) analysis of each coating were done to "fingerprint" the samples evaluated in the laboratory. The results of the IR and GC work are shown in Appendix A. The laboratory procedures used are described below. Additional vendor information and safety sheets for the MIL-P-24441, Ameron, and MIL-P-4556 systems are included in Appendix B.

Test Methods

1. Pigment content (Federal Test Method Std. No. 141B, Method 4021, 1 February 1979).

Apparatus: IEC International Centrifuge, Size 2, Model K, 8-unit head. Sartorius Analytical Balance.

Extraction mixture: 50 percent toluene, 50 percent acetone.

Procedure: In a weighed centrifuge tube, approximately 15 g of the sample (coating or coating component) were weighed to the nearest 0.0001 g. Twenty-five milliliters of the extraction mixture were added and mixed thoroughly with a glass rod. The rod was washed with more of the mixture from a wash bottle. The material was centrifuged 30 minutes at 2000 rpm, and the clear supernatant liquid was decanted. These steps were done twice more with 35 ml of the extraction mixture. After the liquid was drawn off for the last time, the tube was set in a steam bath for 10 minutes, put in a 105°C oven overnight, cooled in a dessicator, and weighed. The percentage of pigment was calculated.

2. Total solids

Apparatus: Sartorius Analytical Balance, Aluminum Evaporation Dishes.

Procedure: Into a weighed evaporating dish, approximately 0.5 g of the sample was added and quickly weighed to the nearest 0.0001 g; the dish was put in a 105°C oven for 1-1/2 hours, cooled, and weighed. The percentage of total solids, by weight, was calculated.

Table 3

Characterization Test Results

Coating	Component	Total Solids, Percent	Pigment, Percent	Nonvolatile Vehicle, Percent
MIL-P-24441 Formula 158	A	73.3	50.6	46.0
	B	76.7	29.3	67.0
MIL-P-24441 Formula 152	A	68.8	50.9	36.5
	B	70.8	27.7	59.6
MIL-P-23377	A	63.7	40.3	39.2
	B	20.5	0.0*	20.5
MIL-C-22750	A	70.8	5.8	69.0
	B	47.2	9.3	41.8
MIL-C-4556 Primer	A	68.1	48.4	38.2
	B	82.5	0.0	82.5
MIL-C-4556 Topcoat	A	59.4	33.9	38.6
	B	62.5	0.0	62.5
Steelcote 100% Solids	A	96.4	0.0	96.4
	B	97.1	23.7	96.2
Ameron 86	*	33.3	17.8	18.9
Ameron 99HS	*	67.4	36.4	48.7
TS3236-26 Wash Primer	A	32.9	15.7	20.4
	B	1.7	0.0	1.7
TS3236-23 Topcoat	A	64.6	4.4	63.0
	B	16.1	0.0	16.1
MIL-C-83286	A	65.7	32.7	49.0
	B	34.1	0.0	34.1
Irathane 155	A	74.0	4.8	72.7
	B	17.6	0.0	17.6
BMS-10-11K	A	63.5	45.1	33.5
	B	1.7	0.0	1.7

*Not applicable.

3. Nonvolatile vehicle content (Federal Test Method Std. No. 141B, Method No. 4053, 1 February 1980). This method was used to calculate the nonvolatile vehicle (NVV) content from the sum of volatile matter and the pigment solids content:

$$\% \text{ NVV} = \frac{\% \text{ total solids} - \% \text{ pigment}}{100 - \% \text{ pigment}} \times 100$$

4. Gas chromatographic analysis. A gas chromatogram of each mixed coating (as a liquid before curing) and of each thinner was prepared using the following apparatus and conditions:

Instrument:	Hewlett-Packard model 5880A
Detector:	Thermal conductivity detector
Column:	Carbowax 1500, 10 ft
Carrier gas:	Helium
Oven temperature profile:	Initial value = 80°C
	Initial time = 3.00 minutes
	Temperature increase rate = 20°/minute
	Final value = 249°C
	Final time = 7.50 min.
Detector temperature:	225°C
Injector temperature:	225°C
Sample size:	2.5 μl

Sample preparation: Approximately 0.5 ml of the mixed sample was thoroughly mixed with 3 ml of clean pentane in a test tube. The sample was centrifuged at high speed for 10 minutes to remove the resins, pigments, and other nonvolatiles from the solution. A sample of the top layer of the solution was drawn with a syringe and injected into the chromatograph. The gas chromatographic analyses are shown in Appendix A.

5. Infrared analysis. For future reference, infrared spectra were taken of (1) the uncured coating vehicles and (2) the thinners used for their application. The spectra were recorded from 4000 to 200 cm^{-1} on a Perkin Elmer 283B infrared spectrophotometer equipped with an accessory infrared data station.

The clear liquid vehicles and thinners were analyzed in a demountable liquid cell with potassium bromide windows and a 0.010-mm Teflon spacer. Pigmented materials were centrifuged for 5 minutes in a Sharples Super Centrifuge Model #T-41-24 to obtain a vehicle suitable for infrared transmission analysis. Except for removal of the pigments, the vehicles were not altered. The instrumental settings were as follows:

Scan time — 12 minutes
Slit program — normal
Response — 1
Ordinate expansion — 1
Abscissa expansion — 1
Suppression — on.

The infrared analyses are shown in Appendix A.

4 TEST RESULTS

This chapter presents and discusses the physical performance of unpainted and painted specimens before and after immersion in selected liquids, as well as corrosion resistance of each coating during the testing. It includes tabular summaries, general comments, observations, and statistical analyses. Care must be taken when comparing coatings of different types because there were different modes of failure. For example, in the Elcometer adhesion test, some coating systems broke cleanly from the substrate, while other coatings broke between the primer and the topcoat. In the impact tests, some flexible coatings, such as Irathane 155, failed when the topcoat was punctured. Brittle coatings, such as MIL-C-4556, usually failed when the coating cracked at the impact point. It seems acceptable to compare similar coatings when they are applied over the same coating, or over different substrates.

Physical Tests

Tabular Summary - Tasks I and II

Table 4 summarizes the results of the four different tests done on each specimen tested in Tasks I and II.

General Comments

The results of duplicate tests have been averaged. For the Elcometer adhesion test, the units are given in hundreds of pounds per square inch. A (+) in Table 4 indicates a case in which the glue broke before the paint failed. The glue used for this experiment generally broke at 700 to 900 psi. For the scrape adhesion test, the maximum of the testing apparatus was 10 kg. Specimens which did not fail at 10 kg are marked 10+. Results of the impact tests are given for room temperature (23°C) and 4°C; units are in inch-pounds. The maximum range of the test was 80 in.-lb.

Some of the physical test data were analyzed for significant differences by using analysis of variance techniques. Pertinent averages of test results for the various coatings, various thicknesses, and various substrates were compared; the effect of immersion was also evaluated. Interactions among these factors were examined. Tests of significance were conducted at the 0.05 level (i.e., it is 95 percent certain that the differences observed were significant). To simplify the task, only the two best of the five epoxy coatings in Task I were evaluated by this method. The Ameron vinyl system, all of the urethane systems, and all of the Task II candidate coatings were also evaluated.

Performance - Task I: Nonpolyurethane-Coated Specimens - Observations and Statistical Analyses

1. MIL-P-24441 and MIL-C-4556 Systems. A statistical analysis was performed on the physical test data of these two epoxy-polyamide coating systems. The MIL-P-24441 primer and topcoat system was compared with the MIL-C-4556 system for 5-, 10-, and 15-mil thicknesses, and immersed versus not immersed for substrate a. Of the five epoxy systems tested in Task I, these two were

Table 4

Physical Test Results

System	Thickness (mils)	Sub-strate*	Immersion (Yes, No)	Elcometer Adhesion Test**		Scrape Adhesion Test***	Impact Test (23°C)	Impact Test (4°C)	Impact Failure Type
Task I: Nonurethanes									
MIL-P-24441	5	a	N	+	NA	10+	20	26	Crack
over	5	a	Y	8.3	Primer	10+	32	28	(all
MIL-P-24441	10	a	N	+	NA	10+	24	28	specimens)
	10	a	Y	+	NA	10+	33	23	
	15	a	N	+	NA	10+	22	22	
	15	a	Y	+	NA	10+	26	23	
	5	b	N	+	NA	10+	28	28	
	5	b	Y	7.7	Primer	10+	30	27	
	10	b	N	+	NA	10+	34	26	
	10	b	Y	8.5	Primer	10+	29	25	
	15	b	N	+	NA	10+	26	20	
	15	b	Y	+	NA	10+	31	22	
	5	c	N	+	NA	10+	24	20	
	5	c	Y	+	NA	10+	21	24	
	10	c	N	+	NA	10+	22	28	
	10	c	Y	+	NA	10+	25	21	
	15	c	N	+	NA	10+	26	22	
	15	c	Y	+	NA	10+	27	19	
MIL-C-4556	5	a	N	5.3	Topcoat	10+	24	58	Crack
over	5	a	Y	6.8	"	10+	21	27	(all
MIL-C-4556	10	a	N	6.4	"	10+	24	24	specimens)
	10	a	Y	7.2	"	10+	27	39	
	15	a	N	4.1	"	10+	34	30	
	15	a	Y	5.5	"	10+	11	29	
MIL-C-22750	5	a	N	2.5	Primer	7.3	6	8	Debond
over	5	a	Y	1.7	"	7.6	16	10	between
MIL-P-23377	10	a	N	1.5	"	--	20	10	primer and
	10	a	Y	1.4	"	7.6	7	8	topcoat
	15	a	N	0.3	"	10+	18	12	
	15	a	Y	0.5	"	7.5	9	8	
100% solids	5	a	N	+	NA	5.0	10	4	Debond
over	5	a	Y	7.3	Primer	7.0	5	4	between
MIL-P-23377	10	a	N	+	NA	9.0	4	6	primer and
	10	a	Y	9.0	Primer	8.1	4	4	topcoat
	15	a	N	5.5	"	6.1	20	14	(all
	15	a	Y	6.9	"	3.3	8	8	specimens)
MIL-P-23377	5	a	N	1.0	Primer	10+	10	6	Debond
	5	a	Y	2.9	"	10+	10	8	between
	5	b	N	5.3	"	10+	6	14	primer and
	5	b	Y	8.2	"	10+	10	11	topcoat
	5	c	N	+	NA	10+	26	12	(all
	5	c	Y	+	NA	10+	18	32	specimens)
Amercoat 99HS	5	a	N	2.6	Primer	10+	12	14	Puncture
over	5	a	Y	2.3	Topcoat	10+	14	13	(all
Amercoat 86	10	a	N	2.2	Primer	10+	14	18	specimens)
	10	a	Y	1.8	Topcoat	10+	15	19	
	15	a	N	2.4	Primer	10+	32	30	
	15	a	Y	2.3	Primer	10+	29	33	
	5	b	N	2.2	Primer	10+	12	14	
	5	b	Y	2.2	Primer	10+	10	20	
	10	b	N	2.5	Primer	10+	16	22	
	10	b	Y	2.0	Topcoat	10+	19	29	
	15	b	N	2.4	Primer	8.0	34	48	
	15	b	Y	4.9	Primer	8.9	32	52	
	5	c	N	3.1	Topcoat	10+	12	24	
	5	c	Y	2.3	Topcoat	10+	13	40	
	10	c	N	3.0	Topcoat	10+	20	36	
	10	c	Y	1.8	Topcoat	10+	20	33	
	15	c	N	1.6	Primer	8.5	38	50	
	15	c	Y	2.0	Primer	6.0	41	55	

Table 4 (Cont'd)

System	Thickness (mils)	Sub-strate*	Immersion (Yes, No)	Elcometer Adhesion Test**		Scrape Adhesion Test***	Impact Test (23°C)	Impact Test (4°C)	Impact Failure Type
				Task I: Urethanes					
Hughson	5	a	N	4.3	Primer	10+	20	8	Puncture
polyurethane	5	a	Y	5.4	"	10+	50	7	(all
over	5	b	N	2.6	"	10+	49	4	specimens)
Hughson	5	b	Y	7.6	"	10+	56	9	
wash primer	5	c	N	+	NA	10+	80	10	
	5	c	Y	9.4	Primer	10+	60	10	
Hughson	5	a	N	--	--	10+	22	12	Puncture
polyurethane	5	a	Y	3.6	Primer	10+	50	17	(all
over	5	b	N	1.1	"	10+	16	8	specimens)
MIL-P-23377	5	b	Y	4.1	"	10+	49	10	
	5	c	N	+	NA	10+	18	24	
	5	c	Y	+	NA	10+	76	60	
MIL-P-83286	5	a	N	2.6	Primer	7.5	6	2	Debond between
over	5	a	Y	2.6	"	4.0	5	4	primer and
MIL-P-23377	5	b	N	2.9	"	8.5	6	6	topcoat
	5	b	Y	5.4	"	5.8	3	3	(all specimens)
	5	c	N	+	NA	10+	24	28	
	5	c	Y	+	NA	9.6	8	8	
Irathane 155	15	a	N	+	NA	10	40	50	Puncture
over	15	a	Y	9.6	Topcoat	8.1	21	28	(all specimens)
MIL-P-23377	15	b	N	+	NA	5.0	12	10	
	15	b	Y	8.8	Primer	5.1	18	20	
	15	c	N	+	NA	5.0	14	12	
	15	c	Y	+	NA	5.2	15	13	
				Task II					
MIL-C-22750	2	a	None	0.1	Primer	10+	6	4	Debond
over	2	a	Seawater	0.7	"	7.0	4	4	at
MIL-P-23377	2	a	Fuel	0.8	"	6.0	3	3	primer and
	2	a	50/50	0.3	"	6.0	4	4	topcoat
	2	b	None	0.3	"	3.5	2	2	(all specimens)
	2	b	Seawater	2.4	"	7.7	6	5	
	2	b	Fuel	0.9	"	5.9	2	3	
	2	b	50/50	0.9	"	5.1	4	4	
	2	c	None	+	NA	10+	28	62	
	2	c	Seawater	+	NA	10+	38	67	
	2	c	Fuel	+	NA	10+	25	62	
	2	c	50/50	+	NA	10+	12	65	
MIL-C-4556	8	a	None	+	NA	10+	12	14	Crack
over	8	a	Seawater	8.1	Primer	10+	7	13	(all specimens)
MIL-C-4556	8	a	Fuel	7.8	"	10+	7	11	
	8	a	50/50	9.0	"	10+	7	7	
	8	b	None	+	NA	10+	10	10	
	8	b	Seawater	2.8	Primer	10+	6	8	
	8	b	Fuel	7.7	"	10+	5	9	
	8	b	50/50	8.9	"	10+	6	9	
	8	c	None	+	NA	10+	8	10	
	8	c	Seawater	2.6	Primer	10+	9	11	
	8	c	Fuel	7.8	"	10+	5	7	
	8	c	50/50	8.9	"	10+	8	9	

Table 4 (Cont'd)

System	Thickness (mils)	Sub-strate*	Immersion (Yes, No)	Elcometer Adhesion Test**		Scrape Adhesion Test***	Impact Test (23°C)	Impact Test (4°C)	Impact Failure Type
BMS-10-11K	1	a	None	1.7	Topcoat	5.0	44	40	Debond
	1	a	Seawater	1.6	"	5.6	40	47	within
	1	a	Fuel	1.0	"	5.3	3	9	topcoat
	1	a	50/50	0.8	"	5.8	5	10	layers
	1	b	None	1.2	"	6.5	14	16	(all specimens)
	1	b	Seawater	1.4	"	4.8	4	9	
	1	b	Fuel	0.7	"	5.7	3	2	
	1	b	50/50	1.0	"	5.2	2	3	
	1	c	None	+	"	9.0	12	20	
	1	c	Seawater	4.9	"	7.8	26	39	
	1	c	Fuel	6.9	"	7.5	17	24	
	1	c	50/50	5.7	"	8.8	33	38	

* a = hardcoat anodized dichromate sealed; b = hardcoat anodized unsealed; c = chromate conversion coated.
** a "+" signifies that the glue broke before paint failed.
*** 10+ signifies that the adhesion of the coating exceeded the range of measurement of the testing apparatus.
NA -- not applicable; data not obtained.

obviously the best. Figures 10 through 13 show the data for these two coating systems.

a. Elcometer adhesion test: no analysis performed because MIL-P-24441 was obviously better.

b. Scrape adhesion test: no analysis performed because the two coatings are equivalent within the measuring range of this test.

c. Impact test, 23°C: differences were not statistically significant.

d. Impact test, 4°C: differences were not statistically significant. Averages are shown below (in.-lbs):

		Impact, 23°C	Impact, 4°C
MIL-P-24441		26.2	25.0
MIL-C-4556		23.2	34.5
Thickness:	5 mils	24.2	34.8
	10 mils	26.5	28.5
	15 mils	23.2	26.0
Immersed:	Yes	25.0	28.2
	No	24.3	31.3

2. MIL-P-24441. Because the MIL-P-24441 system performed better than the MIL-C-4556 system in one of the physical tests and was equal to the MIL-C-4556 system in the other tests, the MIL-P-24441 data were analyzed again as a separate group. The data were statistically tested to see if thickness, substrate, or 90-day immersion in seawater affected the performance of the system in the physical tests. No statistically significant differences were found. Thus, for MIL-P-24441, the thickness and substrate do not matter, and immersion of the specimen in seawater for 90 days has no effect. Averages for the four physical tests are given below:

	Thickness (mils)			Substrate			Immersed	
	5	10	15	a	b	c	Yes	No
Adhesion (psi x 100)	+	+	+	+	+	+	+	+
Scrape adhesion (kg)	10	10	10	10	10	10	10	10
Impact, 23°C (in.-lb)	25.8	27.8	26.3	26.2	29.7	24.2	28.2	25.1
Impact, 4°C (in.-lb)	25.5	25.2	21.3	25.0	24.7	22.3	23.6	24.4

+ means strength of coating exceeded range of adhesion tester.

		MIL-P-24441		MIL-C-4556	
		IMMERSED		IMMERSED	
		YES	NO	YES	NO
Thickness (mils)	5	+	+	6.8	5.5
	10	+	+	7.2	6.4
	15	+	+	5.5	4.1

Figure 10. Elcometer adhesion.

		MIL-P-24441		MIL-C-4556	
		IMMERSED		IMMERSED	
		YES	NO	YES	NO
Thickness (mils)	5	10	10	10	10
	10	10	10	10	10
	15	10	10	10	10

Figure 11. Scrape adhesion.

		MIL-P-24441		MIL-C-4556	
		IMMERSED		IMMERSED	
		YES	NO	YES	NO
Thickness (mils)	5	32	20	21	24
	10	33	24	27	22
	15	26	24	11	34

Figure 12. Impact 23°C.

		MIL-P-24441		MIL-P-4556	
		IMMERSED		IMMERSED	
		YES	NO	YES	NO
Thickness (mils)	5	28	26	27	58
	10	23	28	39	24
	15	23	22	29	30

Figure 13. Impact 40°C.

3. Ameron Vinyl System. The data for the vinyl system, Amercoat 99HS over Amercoat 86, were also analyzed to see if thickness, substrate, or immersion had any significant effect.

a. Elcometer adhesion test: no statistically significant differences were found for this test. The results of this test are rather low, but as previously stated, the glue used to bond the circular dolly to the coating surface may have more of an effect on this coating than on other types. Averages (psi x 100) are:

Thickness (mils)			Substrate			Immersed	
5	10	15	a	b	c	Yes	No
2.4	2.2	2.6	2.3	2.7	2.3	2.4	2.4

b. Scrape adhesion test: since 14 of the 18 data points were 10 or greater, no comparisons were made. Averages (kg) are:

Thickness (mils)			Substrate			Immersed	
5	10	15	a	b	c	Yes	No
10	10	8.6	10	9.5	9.1	9.4	9.6

c. Impact test 23°C: statistically significant differences were found among substrates and among thicknesses. The 15-mil thickness and substrate c proved to be the best. Immersion in seawater had no effect on the impact resistance at room temperature. The average test values (in.-lbs) are:

Thickness (mils)			Substrate			Immersed	
5	10	15	a	b	c	Yes	No
12.2	17.3	34.3	19.3	20.5	24.0	21.4	21.1

d. Impact test, 4°C: statistically significant differences were found for both substrates and thicknesses. As in the impact test at 23°C, 15 mils and substrate c were the best. Averages (in.-lbs) are:

Thickness (mils)			Substrate			Immersed	
5	10	15	a	b	c	Yes	No
20.8	26.2	46.0	21.2	30.8	41.0	32.2	29.3

The physical test data for the other three nonurethane Task I coatings were not analyzed statistically. However, general comments about the test results follow.

4. MIL-C-22750 Topcoat Over MIL-P-23377 Primer. This epoxy system has very poor adhesion and impact resistance when applied on anodized aluminum (substrate a and b). In the Elcometer adhesion test, the entire coating system was removed, leaving the substrate exposed. During the impact tests, the

coating debonded within the primer layer in an area around the point of impact.

5. Steelcote 100 Percent Solid Topcoat Over MIL-P-23377 Primer. The major drawback of this coating is its poor resistance to damage by impact. The adhesion of this coating is fair, but not as good as many of the other coating systems.

6. MIL-P-23377 Primer — No Topcoat. The Elcometer adhesion test results of this coating are good when the coating is applied over chromate conversion coated aluminum. Scrape adhesion test results were good over all substrates. Impact tests over chromate conversion coated aluminum were slightly better than over anodizing.

Performance - Task I: Polyurethane Coated Specimens - Observations and Statistical Analyses

Test data for the four urethanes were compared to see if differences existed among them or among the three substrates. The effect of immersion was also examined.

1. Elcometer adhesion test: the Irathane 155 coating system was best; substrate c gave significantly better results. The results are shown in Figure 14.

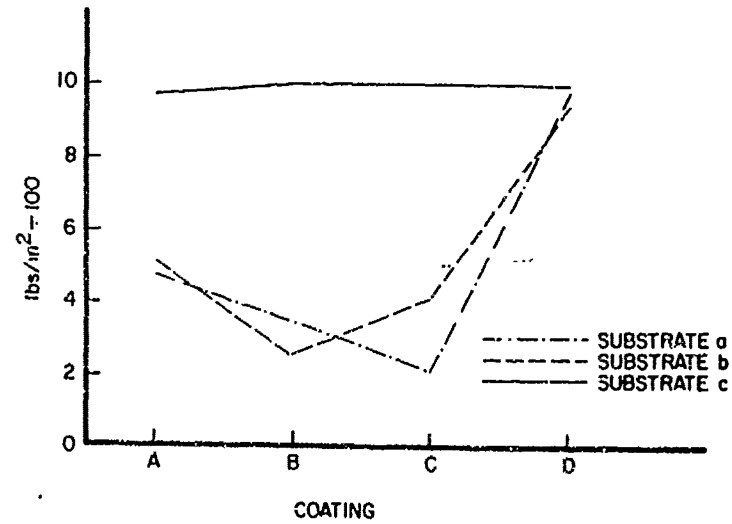
2. Scrape adhesion test: coatings were significantly different and the coating/substrate interaction was significant. The Hughson topcoat over the Hughson wash primer and the Hughson topcoat over the MIL-P-23377 primer with substrate c gave the best results. The results are shown in Figure 15.

3. Impact, 23°C: the only statistical significance was found for the following coatings whose averages were:

Hughson over Hughson	52.5 in.-lb
Hughson over 23377	38.5 in.-lb
MIL-C-83286	8.7 in.-lb
Irathane 155	20.0 in.-lb

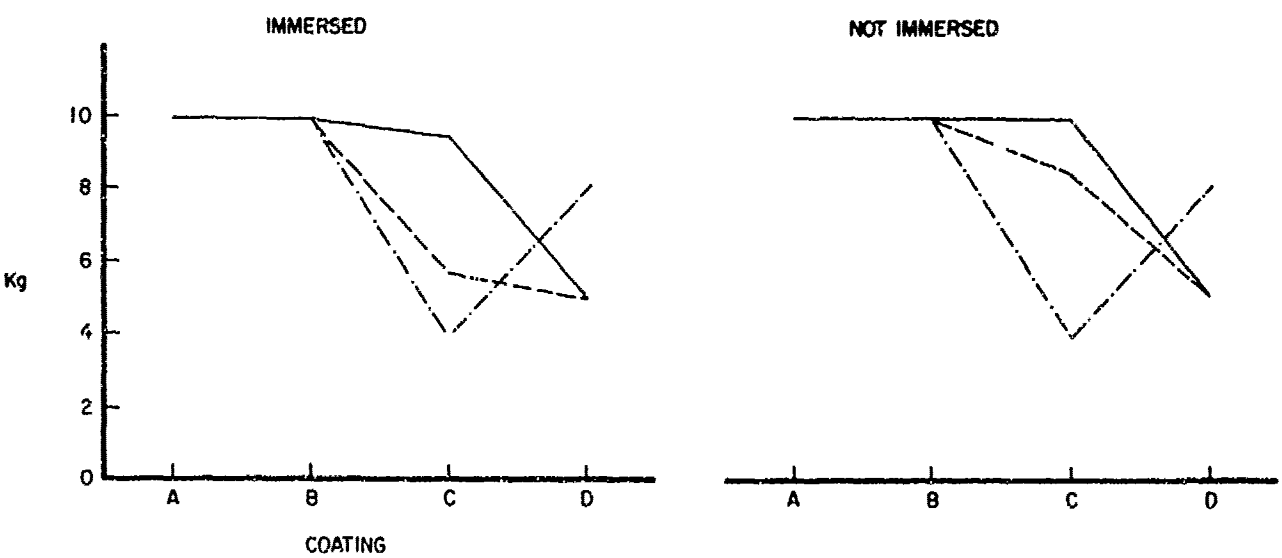
4. Impact, 4°C: no statistically significant differences were found; the four coatings gave similar results, the three substrates gave similar results, and immersion had no effect.

The overall results indicate that all of the polyurethane coatings performed best in the physical tests when applied over chemical conversion coated aluminum (substrate c). The currently used Hughson system performed well in the scrape adhesion and impact tests. The Hughson topcoat over the MIL-P-23377 primer also did well in these tests. The Irathane 155 system was best in the Elcometer adhesion test. The Irathane system is designed to be a high-build polyurethane and was applied at a thickness of 15 mils. Although the test results for the scrape adhesion of the Irathane 155 were somewhat low, the additional thickness of this coating offers protection when the surface has been damaged.



COATING. A HUGHSON TOPCOAT AND PRIMER
B HUGHSON TOPCOAT/MIL-P-23377
C MIL-C-83286/MIL-P-23377
D IRATHANE 155/MIL-P-23377

Figure 14. Elcometer adhesion test results of Task I urethane coatings.



COATING. A HUGHSON TOPCOAT AND PRIMER
B HUGHSON TOPCOAT/MIL-P-23377
C MIL-C-83286/MIL-P-23377
D IRATHANE 155/MIL-P-23377

SUBSTRATE a
SUBSTRATE b
SUBSTRATE c

Figure 15. Scrape adhesion test results of Task I urethane coatings.

The MIL-P-83286 topcoat applied over MIL-P-23377 primer performed fairly well when applied over substrate c. However, the impact resistance of the coating noticeably decreased during the 90-day immersion period in seawater.

Performance - Task II: Nonpolyurethane-Coated Specimens - Observations and Statistical Analyses

The physical test results for the MIL-C-4556 system, the MIL-C-22750 topcoat over MIL-P-23377 primer, and the BMS-10-11K coatings were compared for the three substrates and for the following four immersion levels:

Immersion Level 1: not immersed
Immersion Level 2: seawater
Immersion Level 3: Otto fuel
Immersion Level 4: 50 percent seawater, 50 percent Otto fuel

a. Elcometer adhesion test: statistically significant differences were found among coatings, among substrates, and among immersion levels. The coating/substrate and coating/immersion level interactions were significant (see Figure 16). Overall averages (psi x 100) are:

Coating	Average	Substrate	Average	Immersion Level	Average
MIL-C-22750	3.9	a	3.5	1	5.9
MIL-C-4556	7.8	b	3.2	2	3.8
BMS-10-11K	3.1	c	8.1	3	4.8
				4	5.1

Overall, the MIL-C-4556 system and substrate c are best. Immersion in seawater contributes most to poor adhesion.

2. Scrape adhesion test: statistically significant differences were found among coatings and among substrates. The MIL-C-4556 system had the best scrape adhesion properties, and all of the coatings adhered best to substrate c, chemical conversion coated aluminum. Figure 17 shows the relationship between coatings, substrates, and scrape adhesion. The average test results (kg) are:

Coating	Average
MIL-C-22750	7.6
MIL-C-4556	10+
BMS-10-11K	6.4

Substrate	Average
a	7.6
b	7.0
c	9.4

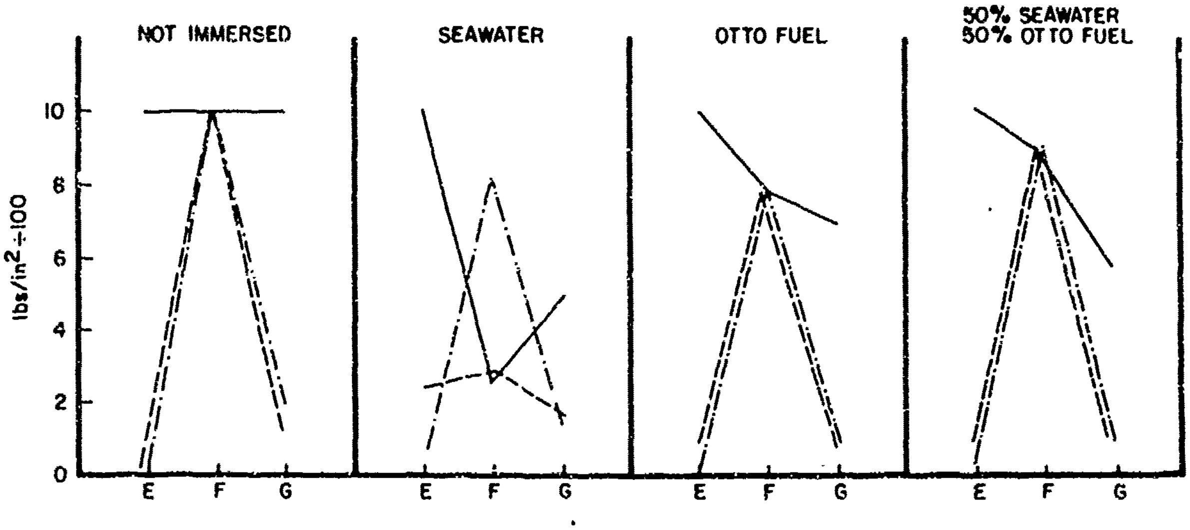


Figure 16. Elcometer adhesion test results of Task II coatings in four immersion tests.

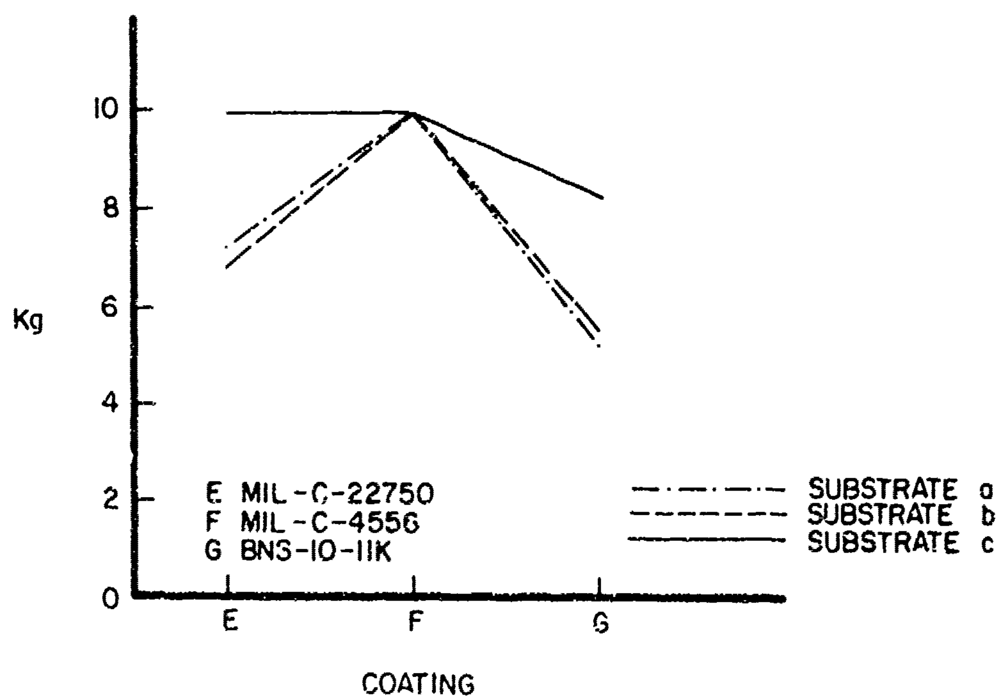


Figure 17. Scrape adhesion test results of Task II coatings.

3. Impact test, 23°C: Impact resistance is not as important for Task II coatings as it is for Task I. The coatings for Task II are tested for application on the interior of torpedo fuel tanks, where the coated surfaces would not be subjected to impact forces. However, for the sake of completeness, these tests were conducted and the the results analyzed. There were no significant differences found among coatings. However, substrate c gave significantly better results than substrates a or b. Averages (in.-lbs) for the different substrates are:

Substrate	Average
a	11.8
b	5.3
c	18.4

4. Impact test, 4°C: significant differences were found among coatings and among substrates. The interactions between Task II coatings, substrates, and impact test results are shown in Figure 18. The best impact resistance was seen for the MIL-C-22750 system over substrate c. Average test values (in.-lbs) for the coatings and substrates are:

Coating	Average
MIL-C-22750	22.1
MIL-C-4556	9.8
BMS-10-11K	22.1

Substrate	Average
a	14.5
b	6.7
c	32.8

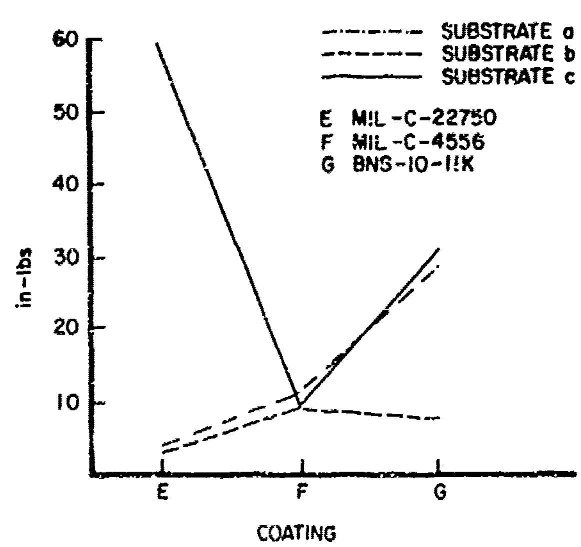


Figure 18. Impact at 40°C test results of Task II coatings.

Immersion Tests

Tabular Summary - Tasks I and II

Table 5 summarizes the results of the immersion tests. Test specimens were immersed for 90 days. Task I specimens were immersed in aerated synthetic seawater. Task II specimens were immersed in seawater, Otto fuel, or a mixture of 50 percent Otto fuel and 50 percent seawater.

Basis for Rating

After 90 days of immersion in seawater, Otto fuel, or a 50/50 mixture of the two, the conditions of each panel were rated according to the following criteria:*

Excellent — No visible damage to the aluminum substrate. Impact points are not corroded or pitted, although the paint surface may be damaged. The score lines may have some oxides, but there is no pitting or widening of the lines.

Good — Less than 5 percent of the surface area is corroded. The 20 or 40 in.-lb impact points show some corrosion extending not more than 1/8 in. from the center of the impact point. Score lines widen to no more than 1/8 in. across.

Fair — 5 to 8 percent of the surface area of the specimen is corroded. The 20 and 40 in.-lb impact points show corrosion 1/8 to 1/4 in. from the center of the impact and usually show a penetration through the panel. Five and 10 in.-lb impact points show a smaller area of corrosion. Score lines widen up to 1/4 in. across and may contain some areas of penetration through the panel.

Poor — More than 8 percent of the surface area of the specimen is corroded. Forty and 20 in.-lb impact points are corroded more than 1/4 in. from the center of the impact point and penetrate through the panel. Five and 10 in.-lb impact points also may penetrate through the panel. Score lines widen to more than 1/4 in. across and penetrate through the panel along much of their length.

These criteria were used for all specimens including damaged and undamaged specimens, specimens that were galvanically coupled, and specimens that were not galvanically coupled. Examples of specimens illustrating the above criteria are given in Figure 19. The examples shown are panels which have been damaged prior to immersion. The panel on the left was impacted, and the panel on the right was scored prior to immersion. In Figure 19 the reverse side of the impacted panel is shown on the left. At the point of 40 in.-lb impact the coating has broken away from the panel. However, the anodizing is completely intact and no damage has occurred to the aluminum substrate. Each

* ASTM D 1654-79 describes a standard method for evaluating coated specimens exposed to corrosive environments. The standard was not used because it is more appropriate for evaluating specimens less severely corroded than the galvanically coupled specimens in this study.

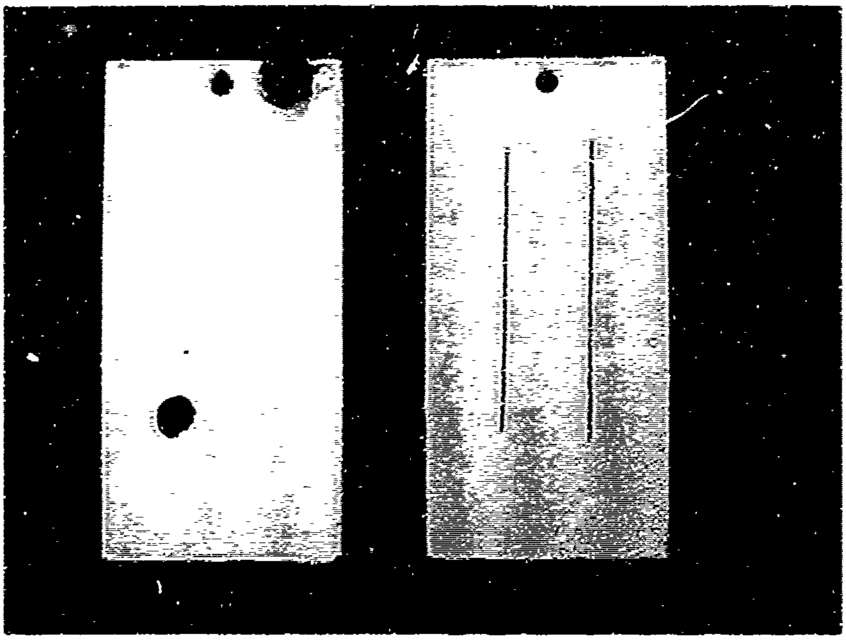
Table 5

Corrosion Resistance of Specimens during 90-Day Immersion

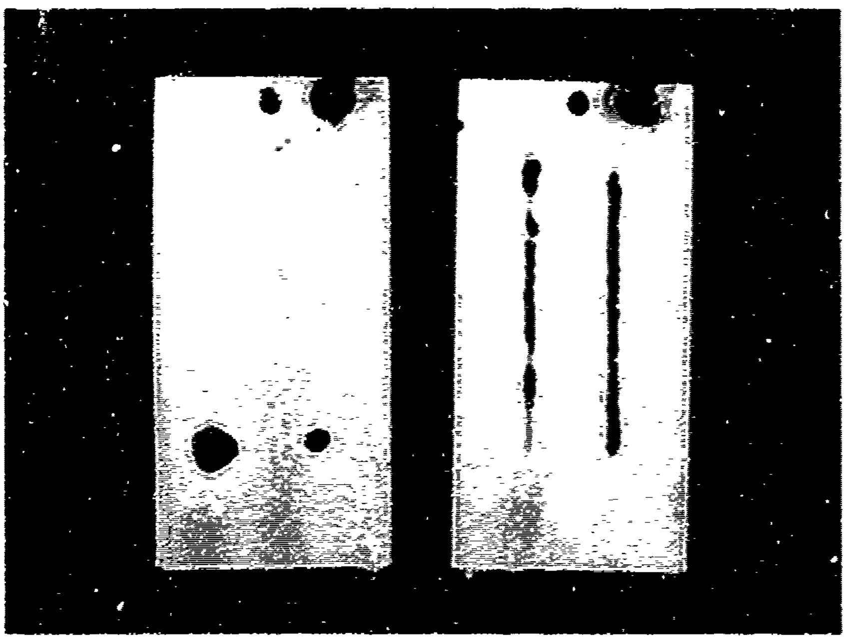
System	Topcoat Thickness (mils)	Sub-strate	Uncoupled Undamaged	Uncoupled Scored	Uncoupled Impacted	Coupled Undamaged	Coupled Scored	Coupled Impacted
Task I: Nonurethanes								
MIL-P-24441	5	a	Excellent	Excellent	Excellent	Excellent	Good	Fair
over	10	a	Excellent	Excellent	Excellent	Excellent	Good	Fair
MIL-P-24441	15	a	Excellent	Excellent	Excellent	Excellent	Good	Fair
	5	b	Excellent	Excellent	Excellent	Excellent	Good	Fair
	10	b	Excellent	Excellent	Excellent	Good	Good	Good
	15	b	Excellent	Excellent	Excellent	Excellent	Poor	Fair
	5	c	Good	Excellent	Excellent	Excellent	Good	Fair
	10	c	Excellent	Excellent	Excellent	Excellent	Fair	Poor
	15	c	Excellent	Excellent	Excellent	Excellent	Good	Poor
MIL-C-4556	5	a	Excellent	Excellent	Good	Excellent	Fair	Good
over	10	a	Excellent	Excellent	Good	Good	Fair	Good
MIL-C-4556	15	a	Excellent	Excellent	Good	Excellent	Fair	Good
MIL-C-22750	5	a	Excellent	Excellent	Good	Excellent	Fair	Fair
over	10	a	Good	Excellent	Good	Excellent	Poor	Poor
MIL-P-23377	15	a	Good	Excellent	Good	Excellent	Poor	Fair
100% Solids	5	a	Excellent	Excellent	Good	Good	Fair	Fair
over	10	a	Excellent	Excellent	Good	Excellent	Fair	Good
MIL-P-23377	15	a	Excellent	Excellent	Good	Fair	Fair	Fair
MIL-P-23377	5	a	Fair	Excellent	Good	Excellent	Good	Good
	5	b	Fair	Excellent	Fair	Excellent	Good	Good
	5	c	Good	Excellent	Good	Excellent	Good	Good
Amercoat 99HS	5	a	Excellent	Excellent	Good	Good	Fair	Fair
over	10	a	Excellent	Excellent	Good	Good	Fair	Fair
Amercoat 86	15	a	Excellent	Excellent	Good	Good	Fair	Good
	5	b	Excellent	Excellent	Excellent	Fair	Good	Poor
	10	b	Excellent	Excellent	Excellent	Good	Good	Fair
	15	b	Excellent	Excellent	Excellent	Excellent	Good	Good
	5	c	Excellent	Excellent	Excellent	Fair	Good	Poor
	10	c	Excellent	Excellent	Excellent	Good	Good	Poor
	15	c	Excellent	Excellent	Excellent	Excellent	Good	Good
Hughson polyurethane	5	a	Good	Fair	Excellent	Fair	Fair	Good
over	5	b	Excellent	Fair	Excellent	Fair	Poor	Poor
Hughson wash primer	5	c	Excellent	Excellent	Excellent	Fair	Fair	Good
Hughson polyurethane	5	a	Excellent	Excellent	Excellent	Good	Fair	Good
over	5	b	Good	Excellent	Excellent	Good	Good	Poor
MIL-P-23377	5	c	Excellent	Excellent	Excellent	Excellent	Fair	Good
MIL-P-83286	5	a	Good	Good	Good	Fair	Fair	Good
over	5	b	Excellent	Good	Good	Poor	Fair	Fair
MIL-P-23377	5	c	Excellent	Excellent	Excellent	Fair	Fair	Good
Irathane 155	15	a	Excellent	Excellent	Excellent	Excellent	Fair	Good
over	15	b	Excellent	Excellent	Excellent	Excellent	Fair	Good
MIL-P-23377	15	c	Excellent	Excellent	Excellent	Excellent	Good	Excellent

Table 5 (Cont'd)

System	Topcoat Thickness (mils)	Sub-strate	Uncoupled Undamaged	Uncoupled Scored	Uncoupled Impacted	Coupled Undamaged	Coupled Scored	Coupled Impacted
				Task II				
MIL-C-22750	Seawater	a	Excellent	Excellent	Poor	Poor		
over	Otto fuel	a	Excellent	Excellent	Excellent	Excellent		
MIL-P-23377	50/50	a	Good	Excellent	Poor	Poor		
	Seawater	b	Good	Excellent	Poor	Poor		
	Otto fuel	b	Excellent	Excellent	Excellent	Excellent		
	50/50	b	Good	Excellent	Fair	Poor		
	Seawater	c	Excellent	Excellent	Poor	Fair		
	Otto fuel	c	Excellent	Excellent	Excellent	Excellent		
	50/50	c	Good	Excellent	Poor	Poor		
MIL-C-4556	Seawater	a	Excellent	Excellent	Fair	Fair		
over	Otto fuel	a	Excellent	Excellent	Excellent	Excellent		
MIL-C-4556	50/50	a	Good	Good	Excellent	Poor		
	Seawater	b	Excellent	Good	Good	Fair		
	Otto fuel	b	Excellent	Excellent	Excellent	Excellent		
	50/50	b	Excellent	Good	Good	Poor		
	Seawater	c	Excellent	Good	Fair	Good		
	Otto fuel	c	Excellent	Excellent	Excellent	Excellent		
	50/50	c	Good	Good	Fair	Poor		
BMS-10-11K	Seawater	a	Excellent	Excellent	Fair	Fair		
	Otto fuel	a	Good	Excellent	Excellent	Excellent		
	50/50	a	Excellent	Excellent	Poor	Poor		
	Seawater	b	Excellent	Excellent	Poor	Good		
	Otto fuel	b	Excellent	Excellent	Excellent	Excellent		
	50/50	b	Excellent	Excellent	Poor	Poor		
	Seawater	c	Excellent	Excellent	Poor	Poor		
	Otto fuel	c	Excellent	Excellent	Excellent	Excellent		
	50/50	c	Excellent	Excellent	Poor	Poor		

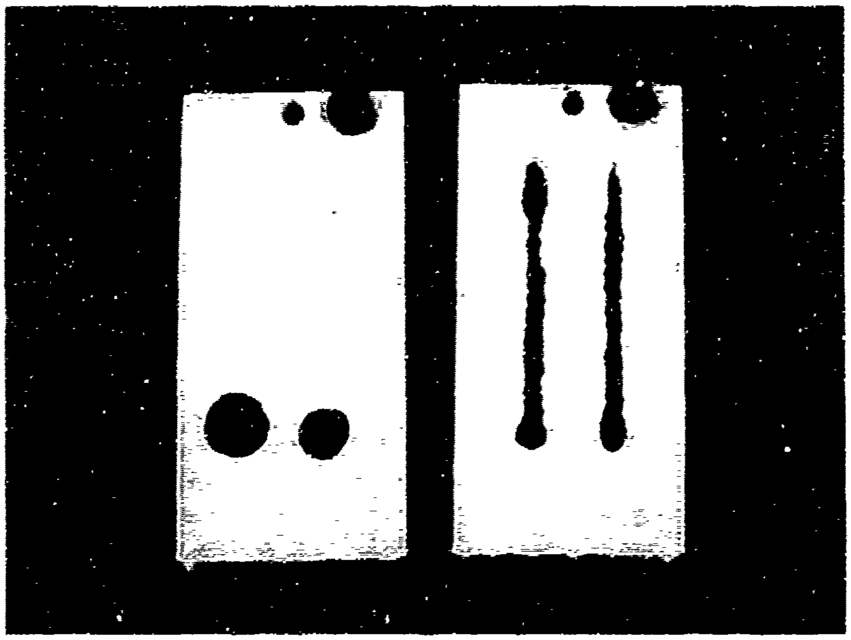


a. Excellent

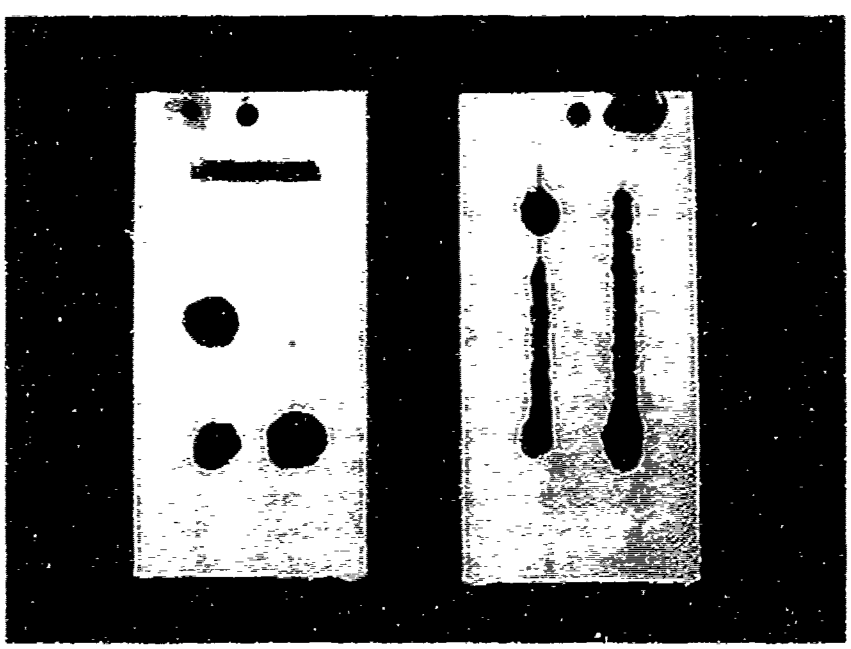


b. Good

Figure 19. Specimens after 90-day immersion.



c. Fair



d. Poor

Figure 19. (Cont'd).

of the scored panels in Figure 19 was scored twice on each side. The score line on the right side of the specimen was cut down to bare aluminum. The score line on the left of each specimen was intended to be cut down to, but not through, the anodizing or conversion coating. However, it was difficult to control the depth of the cut and the bare aluminum substrate was often exposed. Some of the score lines cut to bare aluminum did not corrode significantly during immersion. When the bare aluminum is exposed to seawater some oxides form on the surface of the metal. A scored panel could still meet the criteria for excellent immersion resistance if the corrosion has not extended beyond the original score line in width or in depth. Most of the nongalvanically coupled scored specimens were able to meet this criteria as did many of the coupled specimens. This may have been due to the corrosion inhibitive properties of the coatings and the aluminum pretreatments.

Performance - Task I: Uncoated Specimens - Undamaged

Uncoupled: Bare aluminum panels corroded in seawater over their entire surface, but there was no pitting. Harcoat anodized sealed panels and unsealed panels performed very well with only a few minor areas of corrosion at the edges. Chromate conversion coated panels had a few areas of minor corrosion on their surface and near the edges.

Coupled: Bare aluminum panels that were immersed in seawater for 90 days corroded and pitted over their entire surface (Figure 20). Hardcoat anodized sealed panels corroded only on their edges (Figure 21). Hardcoat anodized unsealed panels corroded on their edges and at a few surface spots where the anodizing might have been flawed or damaged (Figure 22). The chromate conversion coated panels had light corrosion on their surface. None of these spots were large, but there were many of them (Figure 23).

Performance - Task I: Nonpolyurethane-Coated Specimens - Observations

The corrosion performance of the nonpolyurethane-coated paint specimens in Task I is described for each coating, coupled and uncoupled, damaged and undamaged.

1. MIL-P-24441.

Uncoupled: Layers of topcoat were lost at impact points on all panels. The damage caused by impact was more severe on the panels with a 10- and 15-mil topcoat thickness than on the 5-mil-thick coated panels. However, corrosion of the aluminum substrate was minimal. The primer that remained intact protected the substrate from corrosion in the seawater. Neither the scored nor the undamaged panels exhibited corrosion or loss of adhesion. Nearly all specimens in this test were rated excellent.

Coupled: The chemical conversion coated panels corroded more at impact points than did the anodized sealed and anodized unsealed panels. Thickness had less effect. Areas of penetration through the panel at impact points were quite large, up to 1/3 in. from the impact point. Panels coated with 5 mils

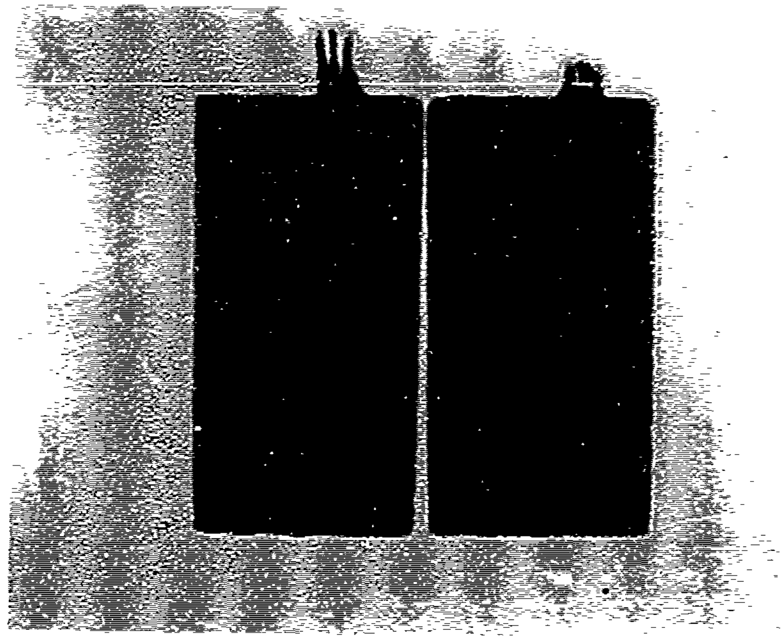


Figure 20. Bare aluminum after 90-day immersion in seawater.

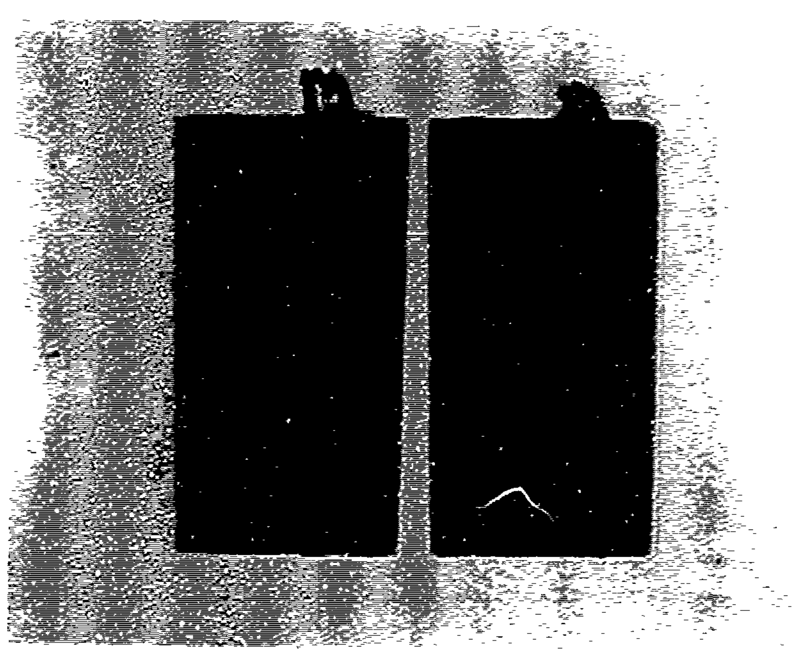


Figure 21. Hardcoat anodized dichromate sealed aluminum after 90-day immersion in seawater.

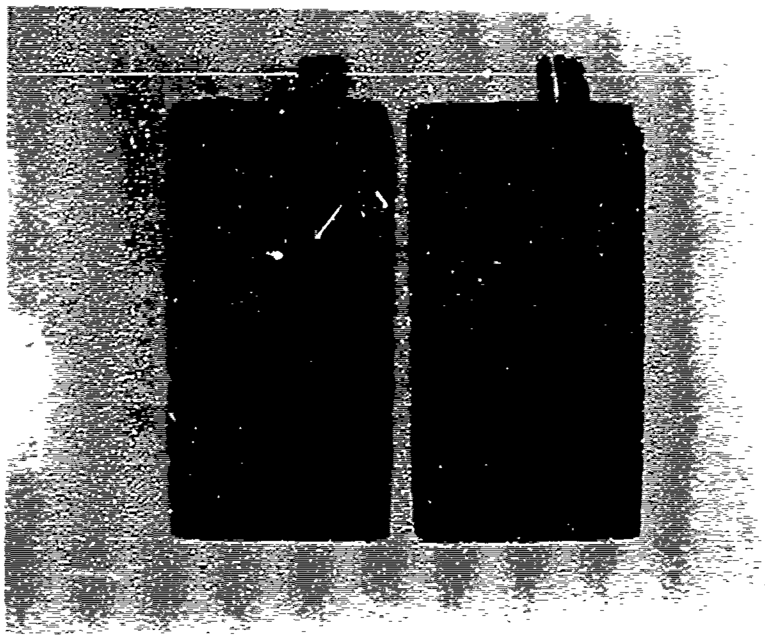


Figure 22. Hardcoat anodized unsealed aluminum after 90-day immersion in seawater.

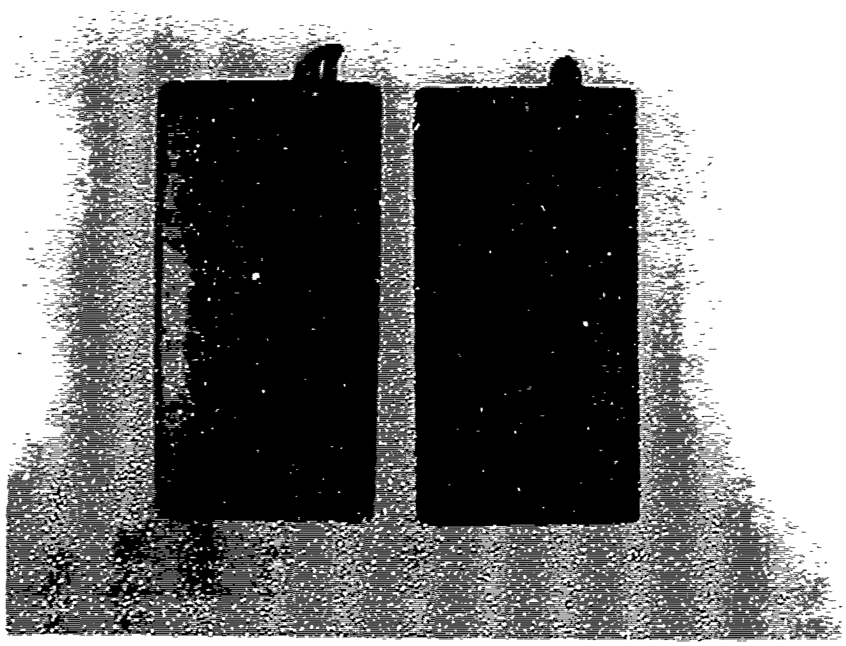


Figure 23. Chromate conversion coated aluminum after 90-day immersion in seawater.

of topcoat showed better corrosion resistance at score lines than did the 10- and 15-mil coated panels. Undamaged panels showed only occasional small areas of corrosion at corners, and most were rated excellent.

2. MIL-C-4556

Uncoupled: There was no corrosion or loss of adhesion around the score lines. Impacted panels showed the removal of the topcoat at 20 and 40 in.-lb impact points, but only the 40 in.-lb area corroded during immersion. The 10-mil-thick coated panels seemed to have better resistance to impact damage than either the 5- or 15-mil-thick coatings, but all three were rated good.

Coupled: Coating thickness had no effect on the corrosion at score lines or impact points. Impact points corroded more on the reverse of the point of impact than on the front. Undamaged panels were rated good to excellent.

3. MIL-C-22750.

Uncoupled: This coating adhered very poorly. Scratching with a fingernail could remove large sections of the coating along a score line. The primer readily debonded from the substrate (anodized chromate sealed aluminum). Blisters up to 3/4 in. in diameter formed around impact points and at edges. The aluminum beneath the blisters was significantly pitted and corroded. Coating thickness did not appear to affect the deterioration of the specimen.

Coupled: Blisters formed around score lines and impact points. Pitting at impact points was severe. Thickness had no apparent effect on the coating's rate of deterioration.

4. The 100 Percent Solids Epoxy Coating

Uncoupled: Panels showed no blistering or corrosion except at impact points. The 10-mil-thick coated panels showed greater resistance to corrosion at impact points than did either the 5- or 15-mil-thick coatings, but the differences were small. The thinner coating did not cover adequately, and the thicker coating was more likely to crack.

Coupled: Impact points corroded to the extent that the aluminum was penetrated except on the 15-mil-thick coating. Scored panels corroded equally for all thicknesses and were rated fair.

5. MIL-P-23377.

Uncoupled: Undamaged and impacted panels were fair to good, but scored panels were rated excellent. The color was somewhat faded because the chromates leached into the seawater. Impact points corroded on the reverse side of the panel. Some pitting of the aluminum was observed at these points.

Coupled: Chromate conversion coated panels showed greater resistance to corrosion at points of impact than did either of the anodized substrates. However, the differences observed were quite small. Score lines showed excellent resistance to corrosion over all three substrates.

6. Ameron Vinyl System

Uncoupled: Overall, this coating had good resistance to corrosion in seawater. There was no loss of adhesion around score lines, except when thicker coatings (10 or 15 mils) were applied over the chemical conversion treated aluminum. Impact points exhibited some corrosion over anodizing. Resistance of the impact points to corrosion depended on coating thickness. Fifteen mils of topcoat provided the best protection from impact damage.

Coupled: Coating thickness had little effect on the corrosion caused by score lines. All were rated fair to good. However, thicker coatings did provide greater corrosion protection at impact points. The Ameron coating was applied to one group of panels very early in the panel preparation period, and to the rest of the panels several weeks later. Thus, some of the panels were allowed a much longer drying time before immersion. Those with the shorter drying period tended to blister, and those with the longer drying period did not. Although there were few blisters, it would be advisable to allow the longest possible drying time before putting Ameron-coated torpedoes in seawater.

Performance - Task I: Polyurethane-Coated Specimens - Observations

1. Hughson Polyurethane Topcoat

The Hughson polyurethane topcoat TS 3236-23 A/B Revision was applied over both the Hughson wash primer TS 3236-26 and the Deft MIL-P-23377.

Uncoupled: Test panels primed with the wash primer had more of a tendency to form small blisters between the primer and the substrate. Also, hardcoat anodized panels had more blisters than did the chromate conversion coated panels. In all other ways the panels seemed to perform equally in a 90-day seawater immersion.

Coupled: All panels had a tendency to blister along the edges, corners, and impact points. However, the panels primed with the Hughson wash primer formed more randomly located blisters on the surface of the panels. The best system for resistance to corrosion at score lines was the MIL-C-23377 primer over the anodized unsealed aluminum, but this system had the least resistance to corrosion around impact points. Overall, the MIL-C-23377 primer performed better than the wash primer, and both systems performed better when applied over chromate conversion coated aluminum.

2. MIL-C-83286.

Uncoupled: The panels pretreated with hardcoat anodizing (sealed or unsealed) exhibited loss of adhesion around score lines, but were still rated good to excellent. The chromate conversion coated panels had no such loss of adhesion. The chemical conversion coated panels also showed no corrosion at impact points (rated excellent), while the other panels showed some pitting (rated good). Undamaged panels performed well over all three substrates.

Coupled: All types of panels showed corrosion at edges and corners; thus, none was rated excellent. The chromate conversion coated panels had the greatest corrosion resistance at impact points. Scored panels showed equal performance over all three substrates and were rated fair.

3. Irathane 155.

Uncoupled: The coating looked dirty after immersion and did not come clean when the panels were rinsed. Overall, the corrosion resistance of the coating was excellent. There was no blistering or corrosion anywhere. All uncoupled panels were rated excellent. There was no loss of adhesion of the coating near the score lines. All three substrates showed equally excellent performance. Impact areas had a break in the topcoat, but the primer was intact, and no corrosion was evident.

Coupled: Impact points had high resistance to corrosion and were rated good to excellent. Scored lines had fair to good corrosion resistance. Chromate conversion coated panels were rated higher than anodized sealed and anodized unsealed panels.

Performance - Task II: Uncoated Specimens - Observations

Seawater: For a discussion of the performance of uncoated specimens in seawater, see Performance - Task I: Uncoated Specimens.

Otto Fuel: None of the specimens, uncoupled or coupled, corroded in Otto fuel.

Fifty percent seawater/50 percent Otto fuel: Uncoupled bare aluminum panels corroded over the entire surface exposed to the seawater layer and in a few areas exposed to the Otto fuel layer. There was no deep pitting. Uncoupled hardcoat anodized sealed and unsealed panels did not visibly corrode. Uncoupled chromate conversion coated panels corroded in a few areas in both the seawater and the Otto fuel layer. Coupled bare aluminum corroded heavily in the seawater layer and more lightly in the portion immersed in the Otto fuel layer (Figure 24). The coupled anodized sealed aluminum test panels corroded on the edges at the water/fuel interface and slightly in the seawater layer (Figure 25). The coupled anodized unsealed panels corroded more than the sealed panels, and they corroded mostly on the edges (Figure 26). The coupled chromate conversion coated panels were corroded over much of the surface exposed to the seawater, with more concentrated areas of corrosion at the seawater/fuel interface (Figure 27).

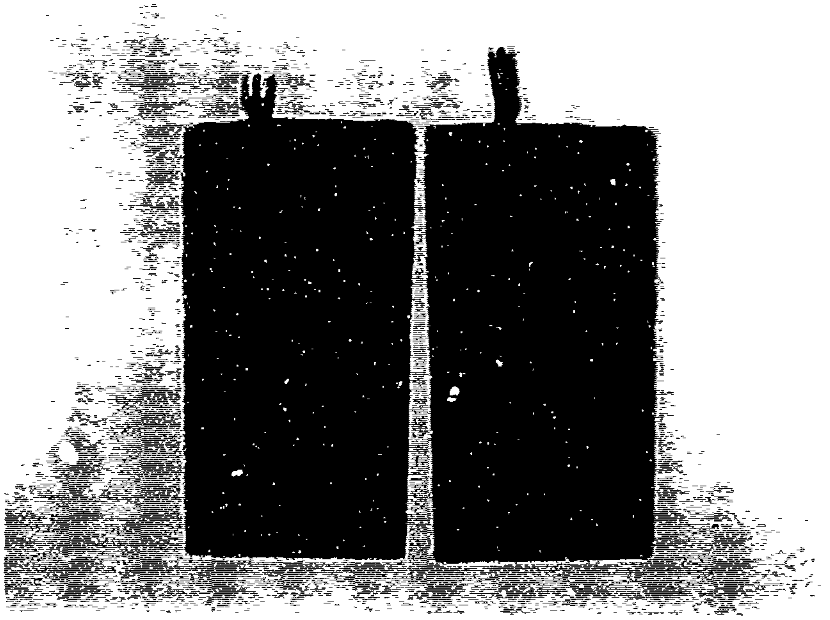


Figure 24. Bare aluminum after 90-day immersion in 50 percent seawater/50 percent Otto fuel.

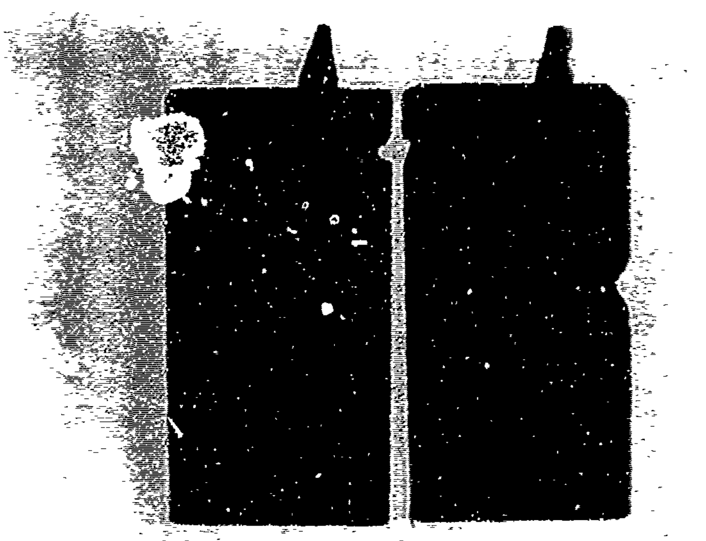


Figure 25. Hardcoat anodized dichromate sealed aluminum after 90-day immersion in 50 percent seawater/50 percent Otto fuel.

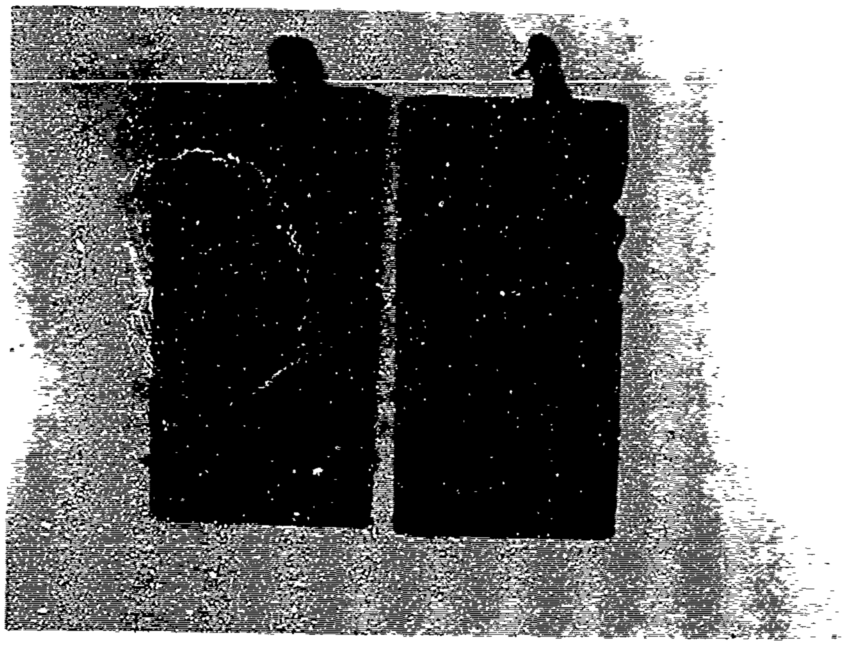


Figure 26. Hardcoat anodized unsealed aluminum after 90-day immersion in 50 percent seawater/50 percent Otto fuel.

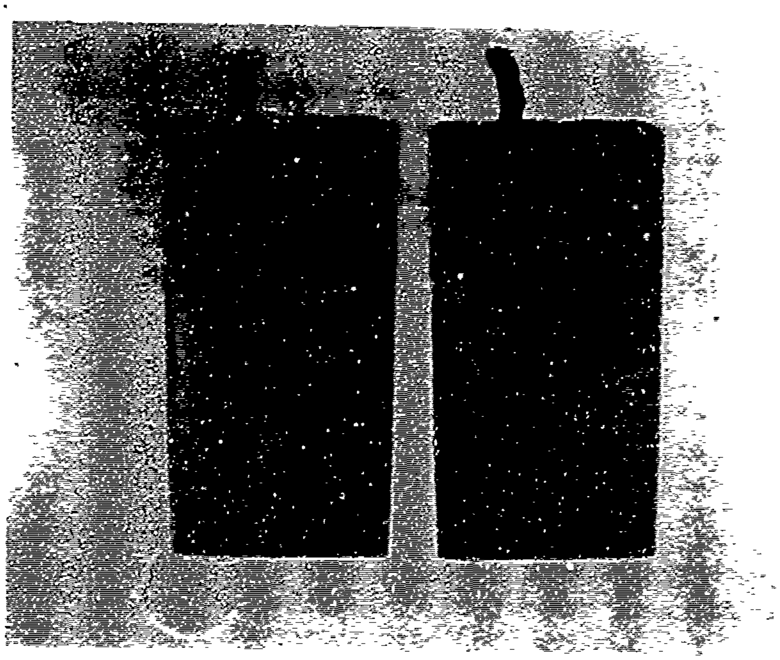


Figure 27. Chromate conversion coated aluminum after 90-day immersion in 50 percent seawater/50 percent Otto fuel.

The coatings discussed below were tested for use on the interior of the torpedo fuel tanks. These coatings were immersed in artificial seawater, Otto fuel, and a mixture of 50 percent Otto fuel and 50 percent seawater. The seawater tanks were aerated; for the seawater and Otto fuel mixture, the seawater layer (the upper layer) was continuously aerated.

1. MIL-C-22750.

Seawater: Uncoupled panels had excellent resistance to corrosion. However, this coating system adhered very poorly. One's fingernail could be used to easily peel paint from the anodized sealed and unsealed panels. The chromate conversion coated panels had good adhesion between the primer and substrate. Coupled panels performed very poorly. There was much loss of metal, and many panels had holes penetrating through the aluminum to the other side. With anodized aluminum, blisters spread out from impact points and score lines. The blisters did not seem to greatly accelerate the corrosion of the area — the anodizing was still intact on the surface of the aluminum.

Otto fuel: This coating is compatible with Otto fuel. No corrosion or softening of the film was evident.

Fifty percent seawater/50 percent Otto fuel: Anodized sealed and unsealed panels suffered more corrosion at edges and corners than did chemical conversion coated panels. However, the chromate conversion coated panels corroded more at the Otto fuel/seawater interface than did the anodized panels. Uncoupled panels were rated good to excellent. Coupled panels were rated fair to poor.

2. MIL-C-4556.

Seawater: There was some loss of adhesion near score lines on uncoupled panels. This problem was more severe on chromate conversion coated panels than on hardcoat anodized panels. Undamaged panels showed no corrosion. Coupled panels corroded only at score lines, and the extent of corrosion was equal for all three substrates. Uncoupled panels were rated good to excellent. Coupled panels were rated fair to good.

Otto fuel: Uncoupled and coupled panels showed no corrosion, loss of adhesion, or deterioration of the coating.

Fifty percent seawater/50 percent Otto fuel: Uncoupled scored panels showed some small blistered areas along the fuel/seawater interface. Undamaged panels had no blisters. Coupled panels showed the greatest corrosion on the chemical conversion coated panels; the damage on these panels was quite severe — nearly 70 percent of the coating was removed and much of the aluminum had corroded away. On the anodized unsealed panels about 20 percent of the coating was removed, and on the anodized sealed panels about 5 percent was removed. Uncoupled panels were rated good to excellent. Coupled panels were rated fair to excellent if undamaged, and poor if scored before immersion.

3. BMS-10-11K.

Seawater: Uncoupled panels showed no corrosion and no loss of adhesion around score lines. Undamaged panels also were rated excellent. Coupled panels were rated poor to fair. Pits up to 1/4 in. in diameter were spread over the entire surface of the panels. This coating was applied as a one-coat system without a primer; any small pinholes or other defects in the film were not covered by additional coats. Coupled panels with score lines had fewer pits, but much corrosion of the scored area. The anodized panels performed somewhat better than the chromate conversion coated panels; there were still corroded areas, but there were fewer corrosion pits.

Otto fuel: Both coupled and uncoupled panels showed excellent resistance to Otto fuel. There was no evidence of coating deterioration or substrate corrosion.

Fifty percent seawater/50 percent Otto fuel: Uncoupled panels showed only some minor areas of corrosion on the edges and at corners, and were rated good to excellent. Coupled panels were all very corroded and received a rating of poor. Anodized sealed panels performed slightly better than anodized unsealed panels; chromate conversion coated panels had the poorest performance. The worst areas were at the fuel/seawater interface and the air/seawater interface.

5 CONCLUSIONS

Task I: Torpedo Exterior Coatings

1. The epoxy systems, MIL-P-24441 and MIL-C-4556, were obviously the best of the five epoxy coatings that were tested in Task I. Both of these epoxies and the epoxy primer MIL-P-23377 had excellent scrape adhesion. MIL-P-24441 was superior to all coatings in the Elcometer adhesion test. The impact strength of MIL-P-24441 and MIL-C-4556 were approximately the same before immersion in seawater. MIL-C-4556 was not quite as resistant after immersion. The impact resistance of MIL-P-23377 was much inferior to either of the other two epoxies. There was no advantage gained in performance when MIL-P-24441 was applied in thicknesses greater than 5 mils. Actually, the surface of the coating chipped more easily at the greater thicknesses. The MIL-P-24441 also had the best corrosion resistance. Based on the test results, the MIL-P-24441 system has the best overall performance of all of the ten candidate coating systems tested for Task I.

2. The Ameron vinyl system (Amercoat 86 primer and Amercoat 99HS topcoat) provides a high degree of corrosion protection, has good impact resistance and adhesion, and (because it is a solution vinyl) should be easily repaired when the original coating is damaged. A 15-mil-thick coating of this vinyl provides much greater protection against damage by impact than does a 10- or 5-mil coat. However, the 15-mil-thick coat has a much longer drying time; adequate time must be allowed before immersing this system. Although the MIL-C-4556 system may have had a slightly better overall performance than the Ameron system, the latter is preferred. The MIL-C-4556 system has corrosion resistance, impact resistance, and adhesion which are only slightly inferior to the MIL-P-24441 system. The Ameron system has properties of flexibility and repairability which are not seen in the two epoxy systems. These properties make the Ameron system a good second choice of the ten systems tested for Task I.

3. Of the four polyurethane systems tested for Task I, Irathane 155 had the best adhesion according to the Elcometer adhesion test. Irathane 155 applied over MIL-P-23377 primer showed superior corrosion resistance during the 90-day seawater immersion tests. The Irathane coating is a high-build polyurethane topcoat and was applied at a dry film thickness of 15 mils. The Irathane polyurethane system would be ranked third among the candidate coatings for Task I.

4. The MIL-P-23377 primer does not adhere well to anodized surfaces. If it is to be used, it should be applied only to chromate conversion coated aluminum. When this primer was applied to anodized surfaces, there were more blisters and much poorer adhesion and impact resistance than when it was applied to the chromate conversion coated aluminum.

5. The effect of coating thickness or type of substrate on performance depends on the specific coating system that is used. There is no one thickness or aluminum pretreatment that is best in all cases.

Task II: Torpedo Interior Fuel Tank Coatings

Of the three candidate coating systems for Task II, the MIL-C-4556 system had the best overall performance when applied over the dichromate sealed, hardcoat anodized 7075 series aluminum. When undamaged, this coating is highly resistant to deterioration in Otto fuel, seawater, or a mixture of the two. When the coating is physically damaged, it does not break away from the damaged area, but remains intact even if corrosion has undercut the coating.

6 RECOMMENDATIONS

This study was very limited in the number of coating systems evaluated. The coatings tested represent different types of coatings and different physical properties. The results of the tests on these coatings may be used to select additional coatings for testing to find the coating system which will best protect torpedo exteriors and the interior fuel tank. Consideration should be given to the following types of coatings:

1. Vinyl-modified epoxies. Coatings of this type are rather new, but have potential. Epoxy coatings have a high degree of chemical resistance, but they tend to be somewhat brittle and inflexible. Incorporating vinyl polymers into epoxy coatings could increase the flexibility and impact resistance of epoxy coatings, while retaining seawater immersion resistance.

2. Vinyl coating systems. The high solids vinyl system manufactured by Ameron performed well, but was somewhat difficult to apply and required a lot of thinning. Alternate vinyl systems should be evaluated, including some low-solids vinyl topcoats.

3. Alternative primers. The MIL-P-23377 epoxy primer manufactured by Deft does not adhere well to anodized surfaces. It is recommended that other primers be evaluated to find a suitable substitute that will have satisfactory adhesion to anodized aluminum. Possible primers include the Boeing specification BMS-10-11K, MIL-P-24441 Formula 158, or possibly a wash primer such as DOD-P-15328.

4. Alternative application methods. The initial study was limited to coatings applied by conventional spraying methods. Possible alternative coatings may include electrostatically applied epoxy coatings, plasma-sprayed coatings, or low-level heat cured coatings.

In addition to materials, there are several recommendations regarding test procedures. These include both modifications to test procedures previously used and the development of new test procedures. The following changes are recommended:

1. The number of test specimens per coating should be increased from 16 to 18. Six panels each should be allowed for nonimmersion, galvanically coupled immersion, and uncoupled immersion tests. Previously only four panels were allowed for nonimmersion tests. Statistical comparisons are more useful when equal numbers of specimens are used for each test.

2. The characterization of the candidate coatings by standard gas chromatographic analysis is only able to determine the number and relative amounts of volatile materials in each coating. An alternative procedure called pyrolysis gas chromatography is now possible on equipment recently acquired by CERL. In this technique, a solid sample of coating film is pyrolized under controlled conditions, and the volatile pyrolysis products are analyzed by gas chromatography. The resulting chromatogram is characteristic of the particular coating formulation. This characterization method should be used in conjunction with the infrared analysis techniques used in this study.

3. The major limitation of the Elcometer adhesion test is the adhesive used to bond the aluminum dolly to the surface of the coating. Although the best available adhesives were used, it was found that their strength was often less than the bond strength of the test coatings to the subtrate. This test does, however, differentiate between coatings with very low adhesion and those with good adhesive strength. This test therefore continues to be an acceptable method for measuring the adhesive strengths of coatings.

REFERENCES

Otto Fuel II: Safety, Storage and Handling, NAVSEA OP 3368 Fifth Revision (Naval Sea Systems Command, 15 January 1973; Change 1, 15 May 1975).

Standard Test Methods for Adhesion of Organic Coatings, D 2197 (American Society for Testing and Materials [ASTM], 1968).

Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact), D 2794 (ASTM, 1969).

METRIC CONVERSIONS

1 in. = 25.4 mm

1 in.-lb = 1.1298×10^{6} dyne centimeters

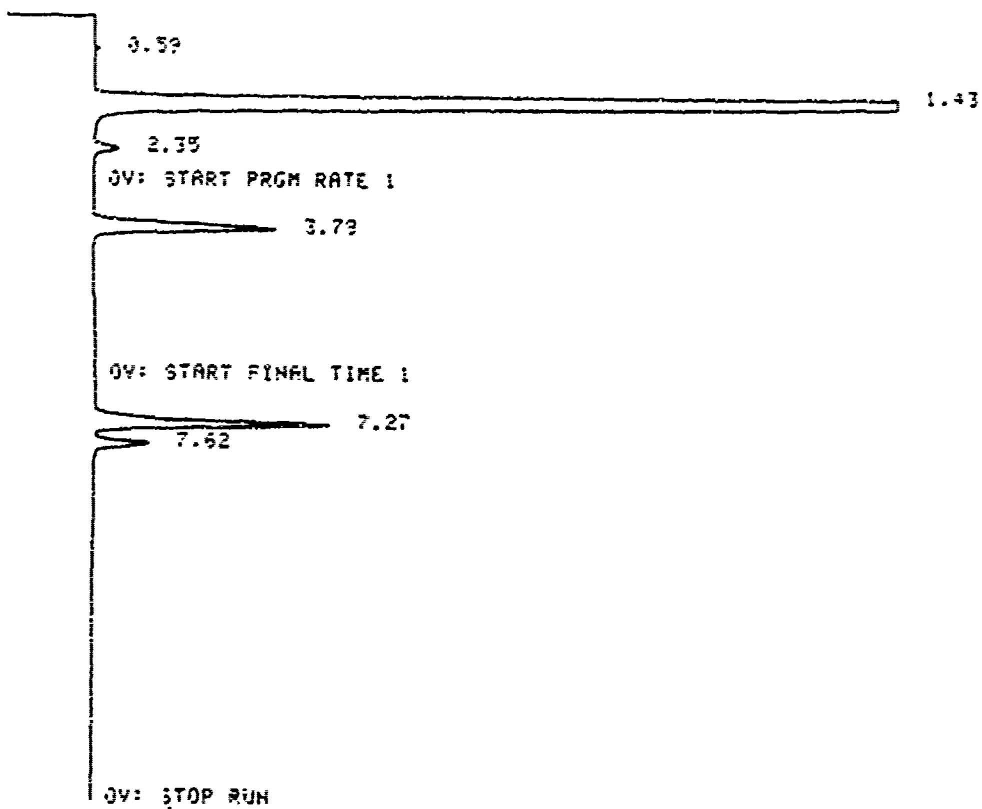
1 mil = 2.54×10^{-5} m

1 psi = 6.9 kPa

APPENDIX A:

GAS CHROMATOGRAPHIC AND INFRARED SPECTRUM ANALYSES

MIL-P-24441 FORMULA 158



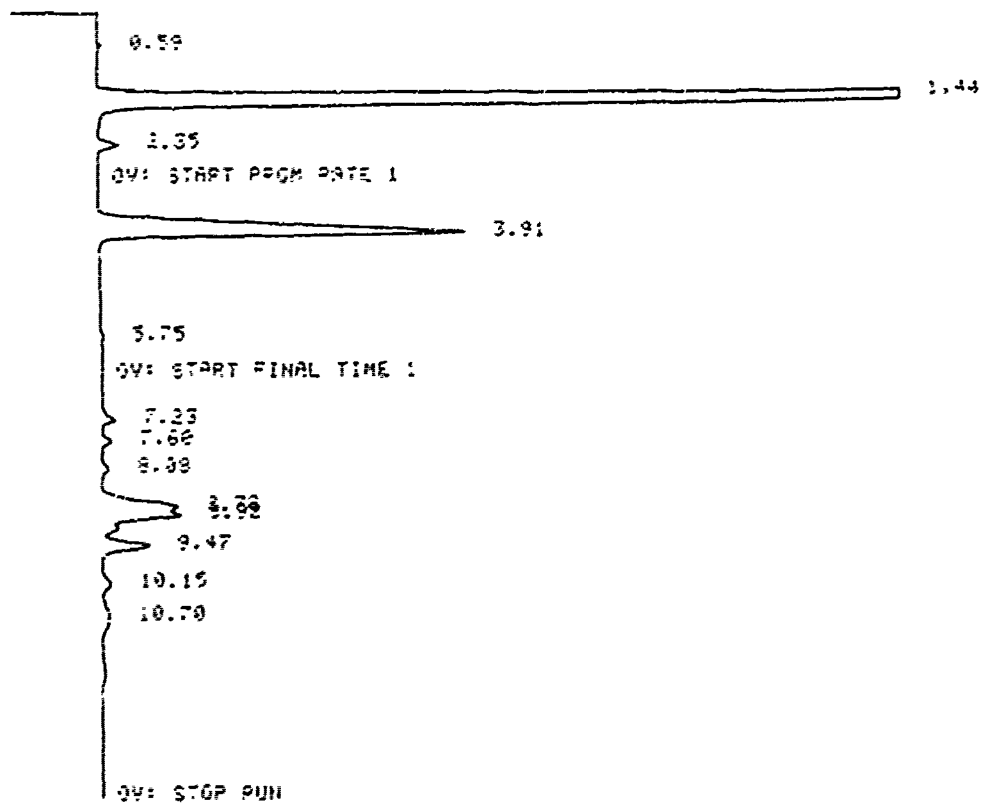
[HP] 5880A MANUAL INJECTION @ 07:55 JUN 21, 1982
AREA %

PT	AREA	TYPE	AREA %
3.78	511655.00	PB	43.093
7.27	562443.00	BV	47.371
7.62	113218.00	VB	9.536

TOTAL AREA = 1187320.00
MULTIPLIER = 1

Figure A1. Gas chromatogram: MIL-P-24441 Formula 158 primer.

MIL-P-24441 FORMULA 152



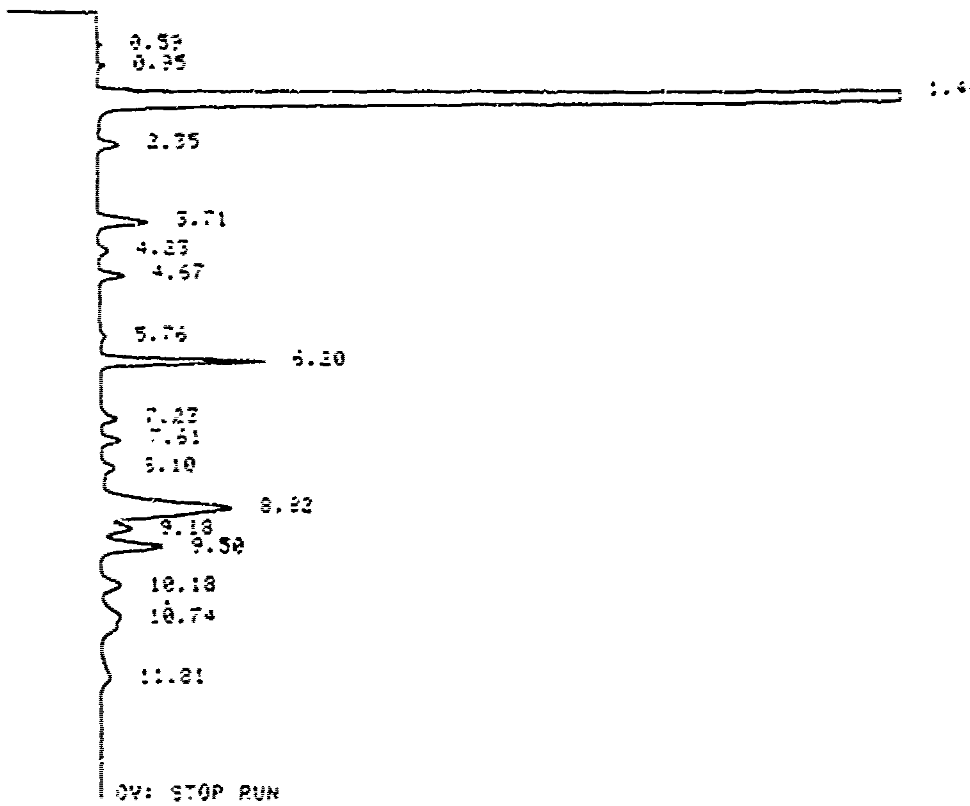
[HP] 5880A MANUAL INJECTION @ 09:40 JUN 21, 1982
AREA %

RT	AREA	TYPE	AREA %
3.91	1380060.00	PB	63.970
5.75	5287.27	BV	0.245
7.23	33165.70	VV	1.537
7.60	21439.90	VP	0.994
8.08	16186.30	PP	0.750
8.78	255532.00	PV	11.845
8.92	223118.00	VV	10.342
9.47	142119.00	VP	6.588
10.15	28784.60	BV	1.334
10.70	51653.40	VP	2.394

TOTAL AREA = 2157350.00
MULTIPLIER = 1

Figure A2. Gas chromatogram: MIL-P-24441 Formula 152 topcoat.

MIL-C-4556 PRIMER



[HP] 5880A MANUAL INJECTION @ 07:29 JUN 23, 1982
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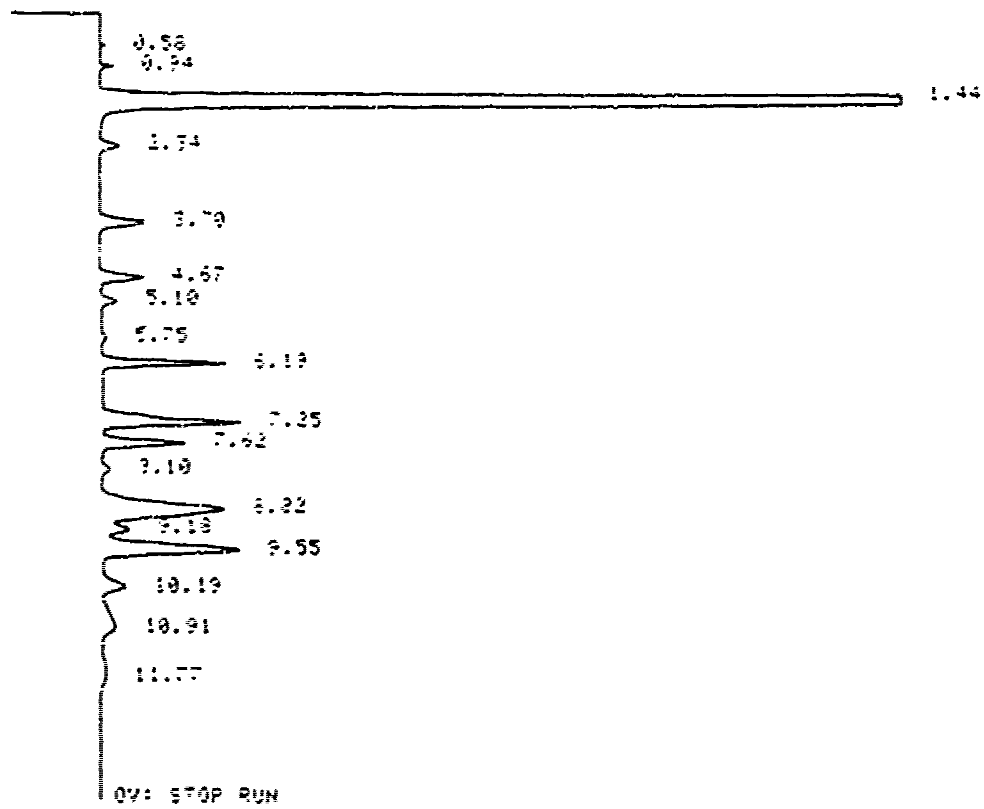
3.71	128008.00	PP	6.883
4.27	23703.30	PP	1.274
4.67	55637.30	PV	2.992
5.76	12686.90	BP	0.658
6.20	301260.00	PB	16.198
7.23	41022.20	VP	2.206
7.61	42430.00	PV	2.282
8.10	54579.20	VV	2.935
8.32	640754.00	VV	34.452
9.18	87240.60	VV	4.691
9.59	193639.00	VV	10.412
10.18	72788.90	VV	3.914
10.74	145917.00	VV	7.846
11.31	60765.20	VP	3.267

TOTAL AREA = 1859949.00
MULTIPLIER = 1

Figure A3. Gas chromatogram: MIL-C-4556 primer.

MIL-C-4556 TOPCOAT



[HP] 5880A MANUAL INJECTION @ 07:06 JUN 23, 1982
AREA %

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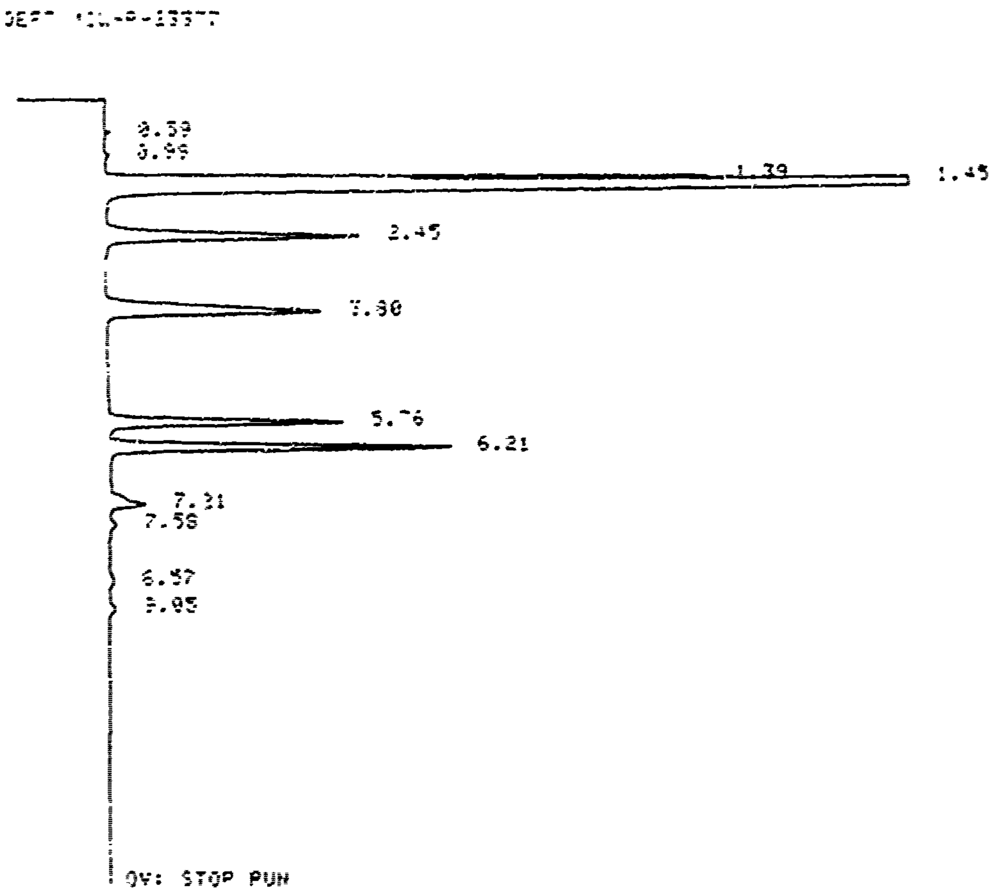
4.67	96821.00	BV	3.961
5.10	34827.00	VV	1.425
5.75	9155.05	BP	0.375
6.19	222776.00	PB	9.114
7.25	360814.00	BV	14.760
7.62	180169.00	VP	7.379
8.10	19149.50	PP	0.783
8.82	605395.00	PV	24.766
9.13	82276.20	VV	3.366
9.55	455521.00	VV	18.635
10.19	100257.00	VV	4.101
10.91	110644.00	VV	4.526
11.77	49279.50	VP	2.016

TOTAL AREA = 2444460.00
MULTIPLIER = 1

Figure A4. Gas chromatogram: MIL-C-4556 topcoat.



[HP] 5880A MANUAL INJECTION @ 12:22 JUN 21, 1982
AREA %

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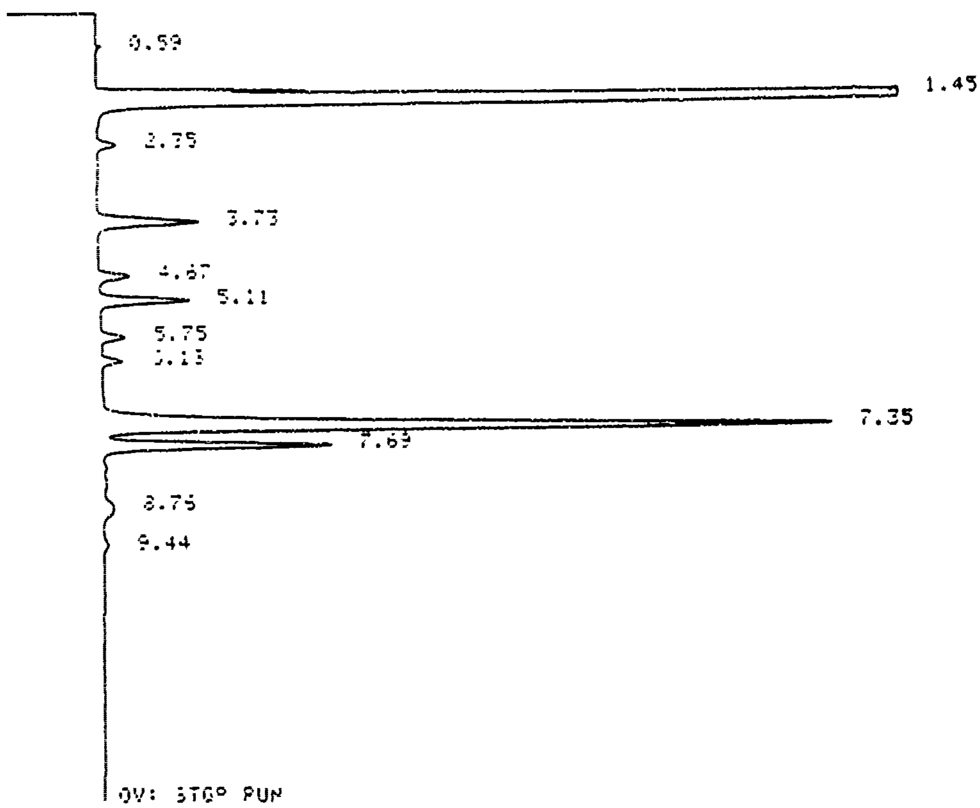
5.76	474452.00	BV	25.184
6.21	651345.00	VB	34.574
7.21	91883.40	VV	4.877
7.53	12663.20	VB	0.672
8.57	16357.60	BV	0.868
9.05	16095.40	VB	0.854

TOTAL AREA = 1883910.00
MULTIPLIER = 1

Figure A5. Gas chromatogram: Deft MIL-P-23377.

MIL-C-22750



[AP] 58808 MANUAL INJECTION @ 12:39 JUN 21, 1982
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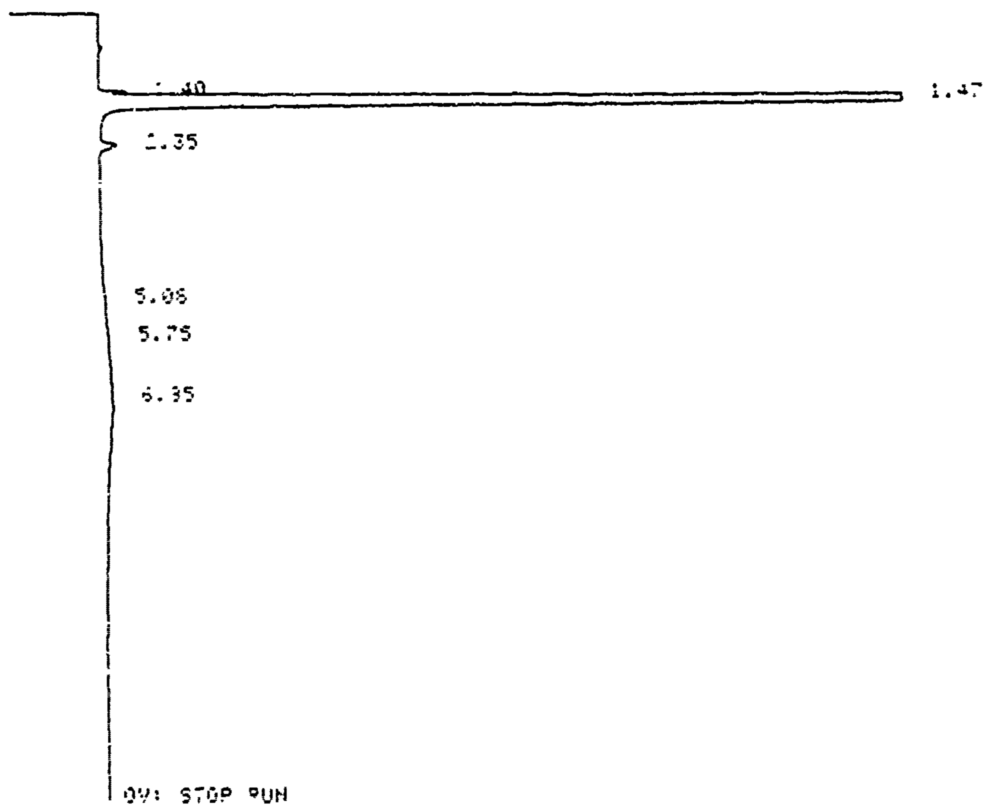
RT	AREA	TYPE	AREA %
3.73	263260.00	PB	7.619
4.67	72161.00	BH	2.089
5.11	20[illegible]41.00	HH	5.865
5.75	62557.30	HH	1.813
6.13	53[illegible]67.00	HH	1.[illegible]04
7.35	2121130.00	HH	61.3[illegible]2
7.69	5354[illegible]1.00	HH	15.497
8.76	89441.79	HH	2.589
9.44	49495.10	HH	1.433

TOTAL AREA = 3455090.00
MULTIPLIER = 1

Figure A6. Gas chromatogram: MIL-C-22750.

STEELCOTE 100% SOLIDS

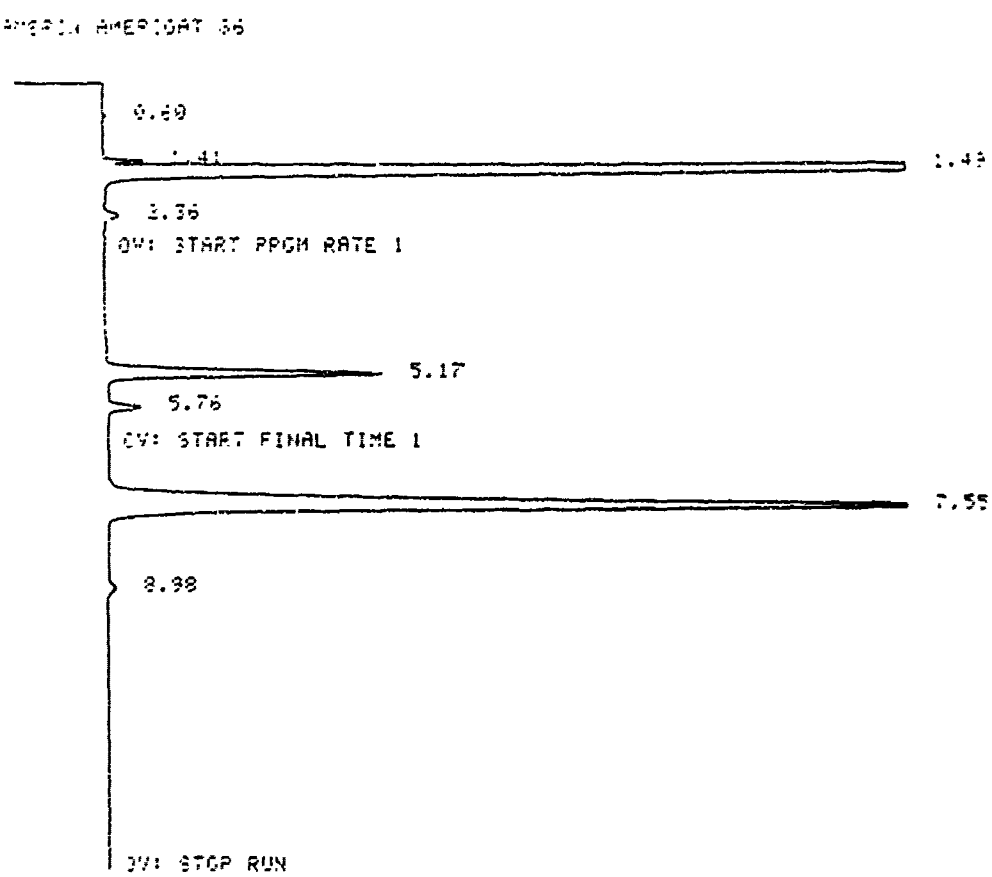


[HP] 5320A MANUAL INJECTION @ 06:43 JUN 23, 1982
AREA %

RT	AREA	TYPE	AREA %
5.06	26012.40	HH	5.258
5.75	56357.40	HH	11.391
6.35	412373.00	HH	83.351

TOTAL AREA = 494743.00
MULTIPLIER = 1

Figure A7. Gas chromatogram: Steelcote 100 percent solids epoxy.



[HP] 5880A MANUAL INJECTION @ 08:37 JUN 21, 1982
AREA %

RT	AREA	TYPE	AREA %
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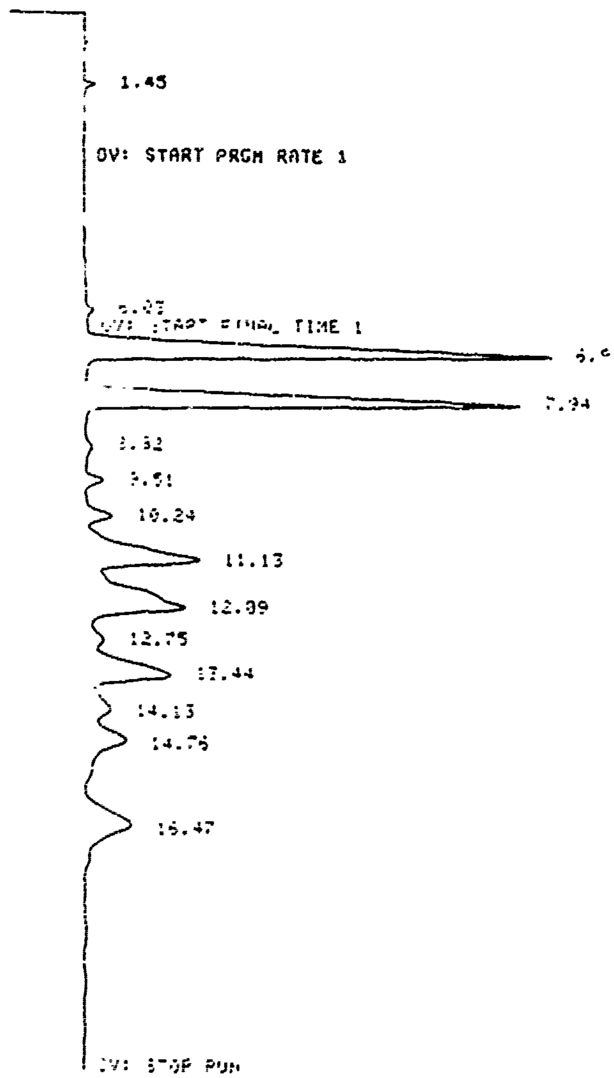
5.76	68699.30	VB	1.737
7.55	3212600.00	PB	81.242
[illegible]	20895.30	PB	0.528

TOTAL AREA = 3954340.00
MULTIPLIER = 1

Figure A8. Gas chromatogram: Amercoat 86 primer.

OVEN TEMP FINAL TIME 15

AMERCOAT 6 THINNER

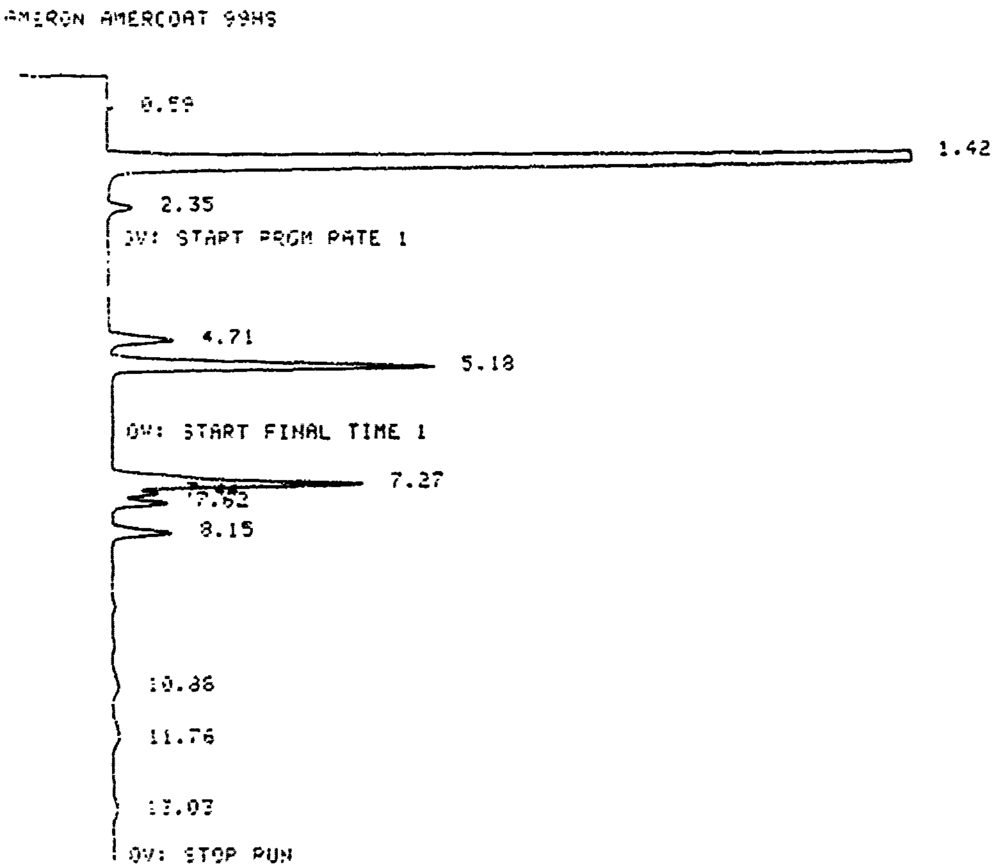


[illegible] 58604 MANUAL INJECTION 9 10:01 JUN 21, 1982
AREA %

RT	AREA	TYPE	AREA %
6.03	44177.60	HH	0.479
6.96	2418440.00	HH	26.222
7.94	2103030.00	HH	22.802
8.82	56467.50	HH	0.612
9.51	84794.30	[illegible]	0.919
10.24	164118..	HH	1.779
11.13	952623.00	[illegible]	10.329
12.09	1091270.06		11.832
12.75	155446.00	[illegible]	1.685
13.44	765326.00	HH	8.299
14.13	280871.00	HH	3.045
14.76	510158.00	HH	5.531
15.47	596370.00	HH	6.466

TOTAL AREA = 9223100.00
MULTIPLIER = 1

Figure A9. Gas chromatogram: Amercoat 6 thinner.



[HP] 5880A MANUAL INJECTION @ 08:17 JUN 21, 1982
AREA %

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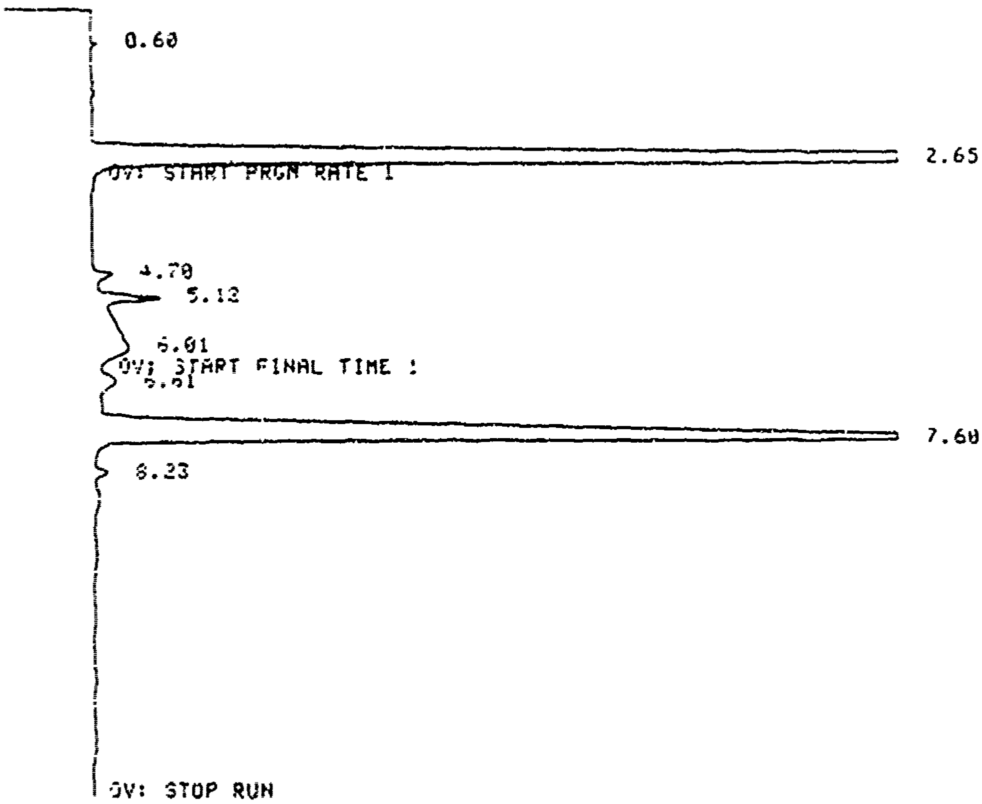
5.18	783571.00	VB	37.982
7.27	669786.00	BV	32.466
7.44	83596.70	VV	4.052
7.62	115664.00	VP	5.607
8.15	142907.00	PB	6.927
10.23	35510.00	PV	1.721
11.76	47035.30	VV	2.280
13.07	24678.70	VP	1.196

TOTAL AREA = 2063030.00
MULTIPLIER = 1

Figure A10. Gas chromatogram: Amercoat 99HS topcoat.

AMERCOAT 9 THINNER

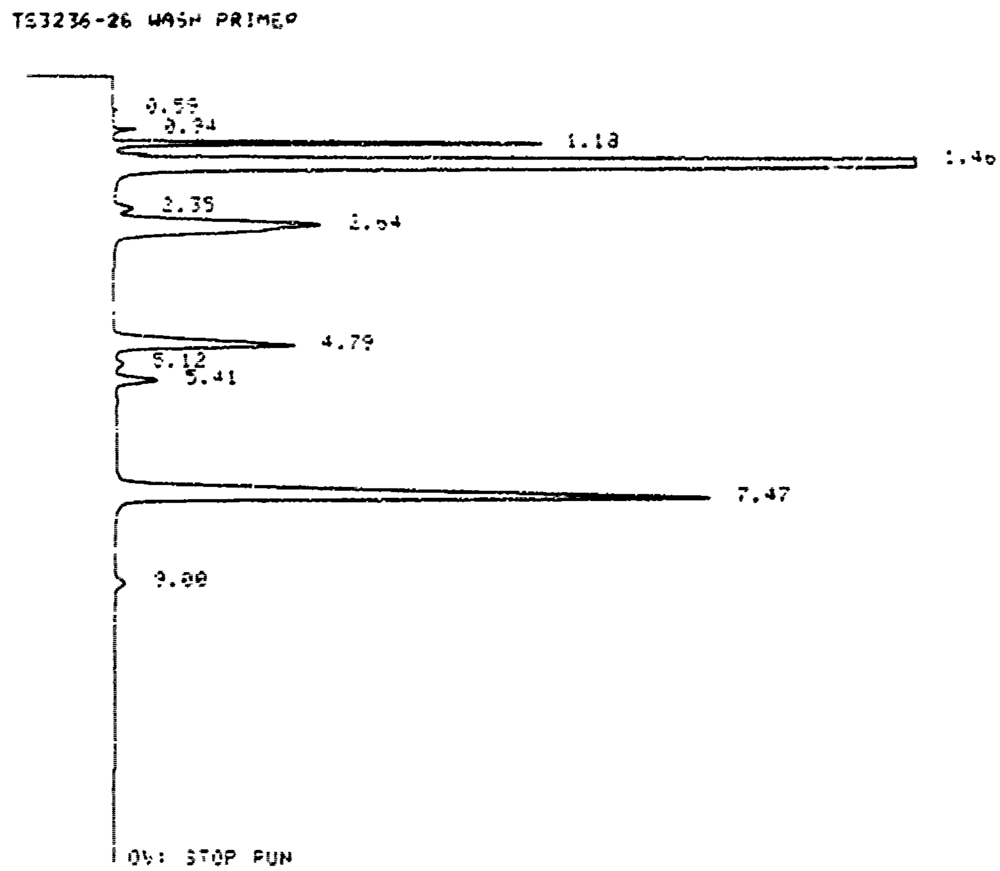


hp 5880A MANUAL INJECTION @ 09:21 JUN 21, 1982
AREA %

RT	AREA	TYPE	AREA %
2.65	5534390.00	VB	52.284
4.70	46626.10	BH	0.440
5.12	171998.00	HH	1.625
6.01	433704.00	HH	4.097
6.61	118197.00	HH	1.117
7.60	4244630.00	HH	40.099
8.23	35796.00	HH	0.338

TOTAL AREA = 10585300.00
MULTIPLIER = 1

Figure A11. Gas chromatogram: Amercoat 9 thinner.



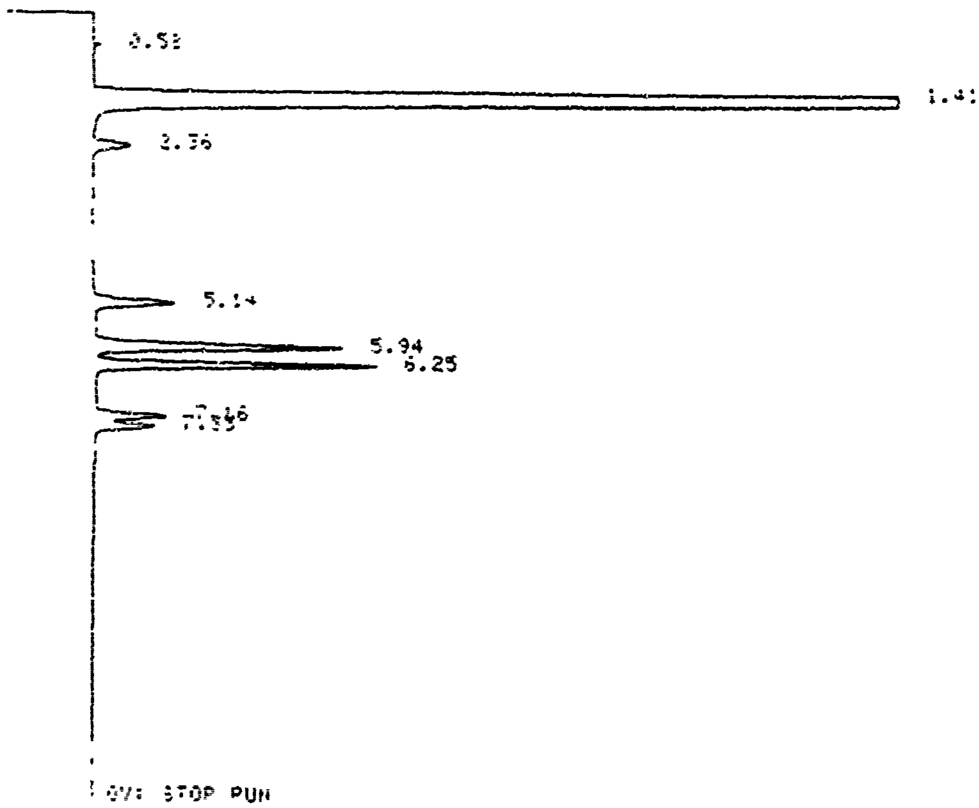
HP 5880A MANUAL INJECTION @ 09:07 JUN 23, 1982
AREA %

RT	AREA	TYPE	AREA %
1.18	428829.00	VV	11.475
2.64	834794.00	VB	22.339
4.79	490960.00	SV	13.138
5.12	22791.30	VV	0.610
5.41	91133.40	VV	2.439
7.47	1839450.00	VB	49.223
9.00	29025.00	PH	0.777

TOTAL AREA = 3736920.00
MULTIPLIER = 1

Figure A12. Gas chromatogram: Hughson TS 3236-26 wash primer.

HUGHSON POLYURETHANE TOPCOAT



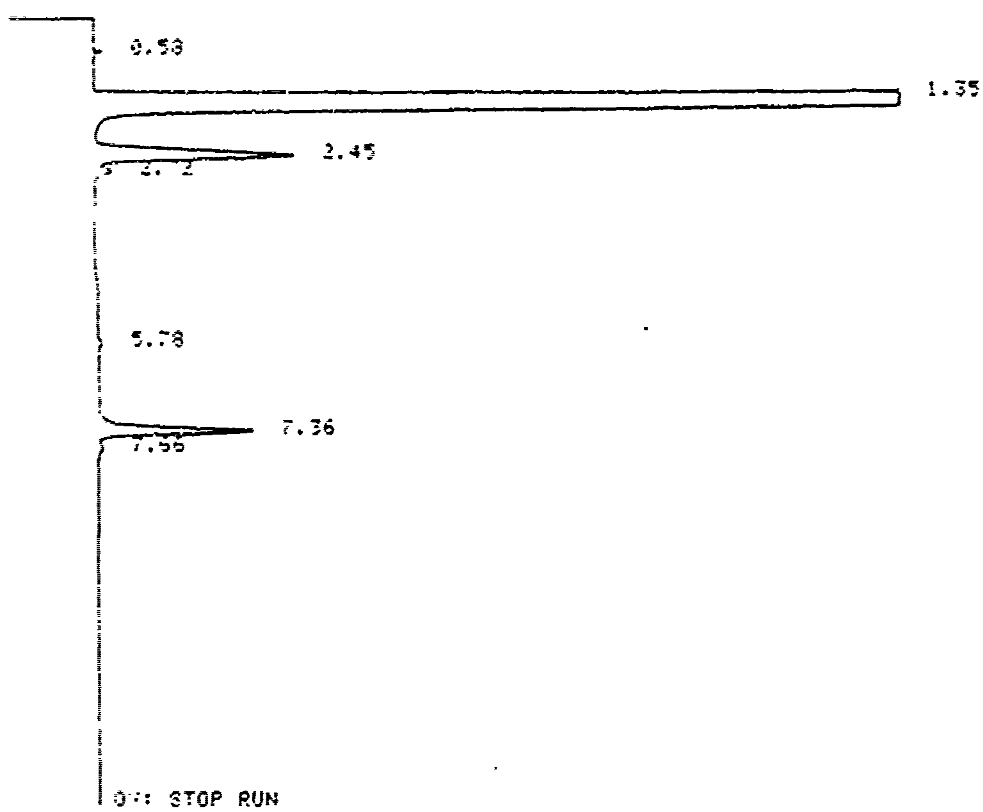
HP 3390A MANUAL INJECTION @ 15:30 OCT 25, 1982
AREA %

RT	AREA	TYPE	AREA %
5.14	179521.00	BV	12.067
5.94	538857.00	BV	36.221
6.25	520301.00	VB	34.974
7.16	137866.00	VV	9.267
7.33	111138.00	VP	7.471

TOTAL AREA = 1487680.00
MULTIPLIER = 1

Figure A13. Gas chromatogram: Hughson TS 3236-23 topcoat.

MIL-C-83206



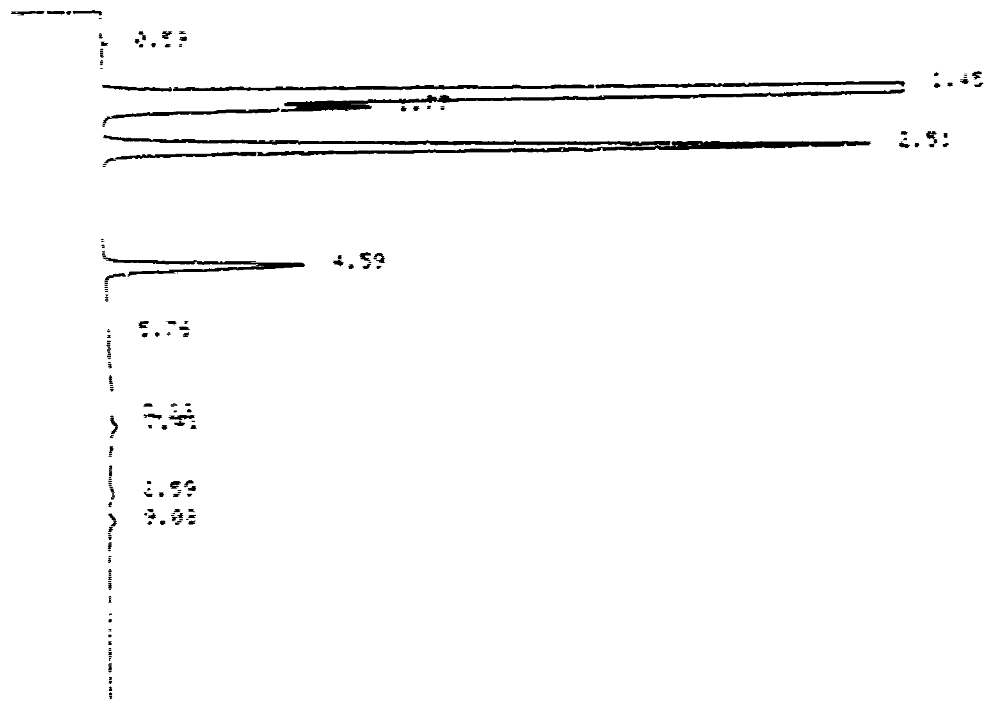
HP 5880A MANUAL INJECTION @ 16:03 OCT 25, 1982
AREA %

RT	AREA	TYPE	AREA %
2.72	41124.10	VP	9.558
5.73	13095.59	PV	3.044
7.36	366190.00	BV	85.107
7.66	9858.53	VB	2.291

TOTAL AREA = 430268.00
MULTIPLIER = 1

Figure A14. Gas chromatogram: MIL-C-83286.

IRATHANE C-155



STOP RUN

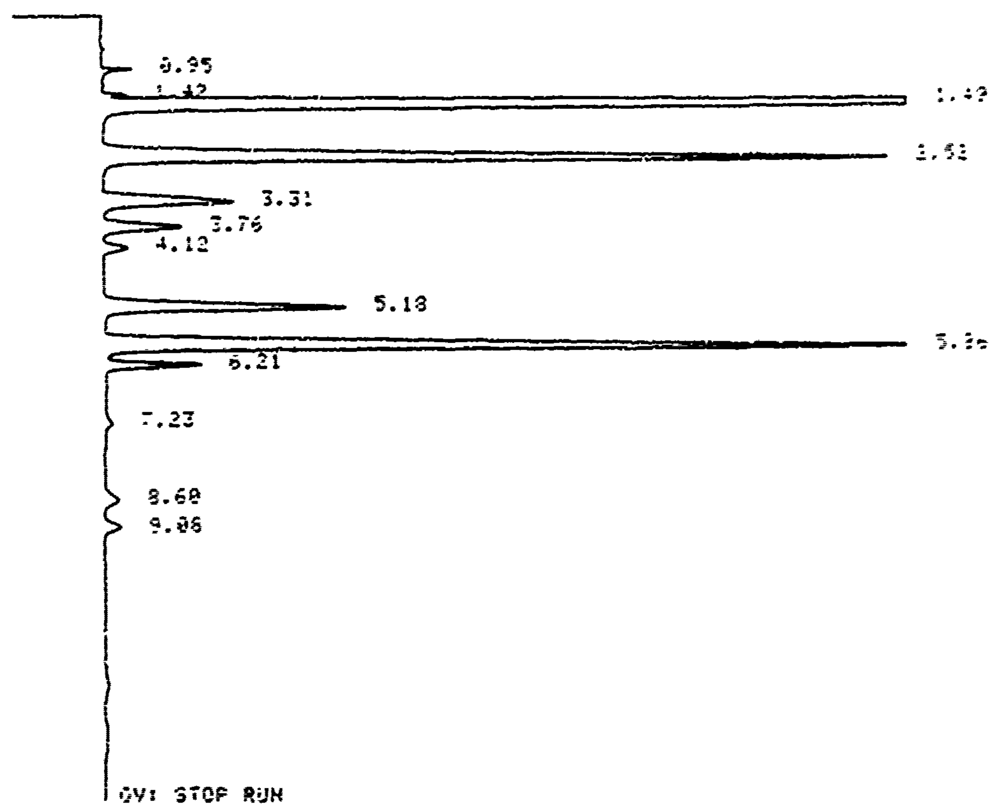
[illegible] 5790A MANUAL INJECTION @ 13:34 JUL 12, 1982
AREA %

RT	AREA	TYPE	AREA %
2.51	1964130.00	VB	74.609
4.59	466762.00	BV	17.730
5.76	27155.90	VV	1.032
7.11	97410.00	VV	3.700
7.41	48510.90	VV	1.843
8.59	12494.10	BP	0.475
9.08	16109.90	PB	0.612

TOTAL AREA = 2632570.00
MULTIPLIER = 1

Figure A15. Gas chromatogram: Irathane 155.

BMS:10-11K



[>] 5890A MANUAL INJECTION @ 13:16 JUN 21, 1982
AREA %

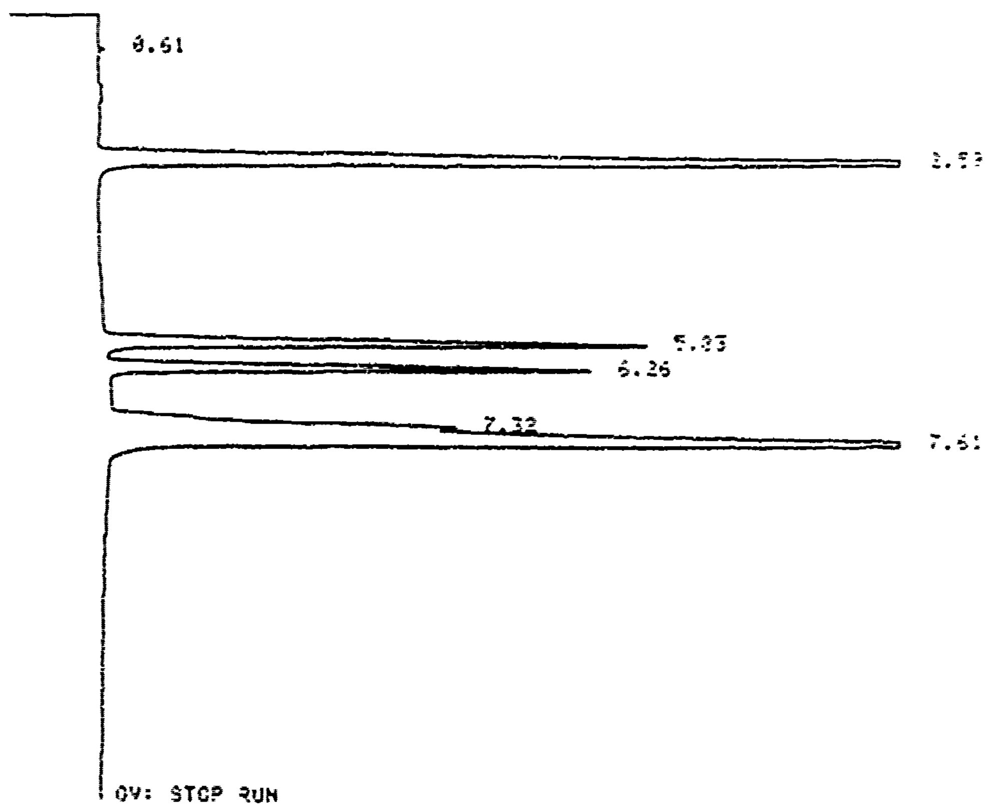
RT	AREA	TYPE	AREA %
2.52	1966420.00	VB	35.484
3.31	364154.00	BV	6.571
3.76	192575.00	VV	3.475
4.12	56727.70	VP	1.024
5.13	612168.00	PV	11.047
5.26	2065090.00	VV	37.265
6.21	168062.00	VB	3.033
7.23	20029.50	VV	0.361
8.60	49702.10	PV	0.897
9.06	46713.00	VB	0.843

TOTAL AREA = 5541640.00
MULTIPLIER = 1

PAGE

Figure A16. Gas chromatogram: BMS-10-11K.

DEFT CHEMICAL COATINGS IS-143
MIL-T-81772/AS



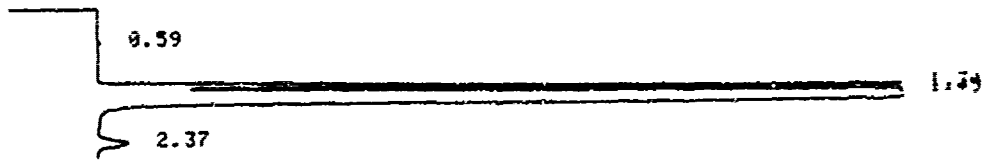
HP 5880A MANUAL INJECTION @ 13:46 JUL 22, 1982
AREA %

RT	AREA	TYPE	AREA %
2.59	2897110.00	VB	28.140
5.33	1338190.00	HH	12.993
6.26	1068070.00	HH	10.374
7.32	1057630.00	HH	10.273
7.61	3934490.00	HH	38.215

TOTAL AREA = 10295400.00
MULTIPLIER = 1

Figure A17. Gas chromatogram: MIL-T-81772/AS thinner.

PENTANE




```
[HP] 5880A  MANUAL INJECTION @ 15:59  OCT 25, 1982
AREA %

   RT              AREA  TYPE    AREA %

TOTAL AREA = 0.00
MULTIPLIER = 1

PAGE
```

Figure A18. Gas chromatogram: solvent used for preparing samples — pentane.

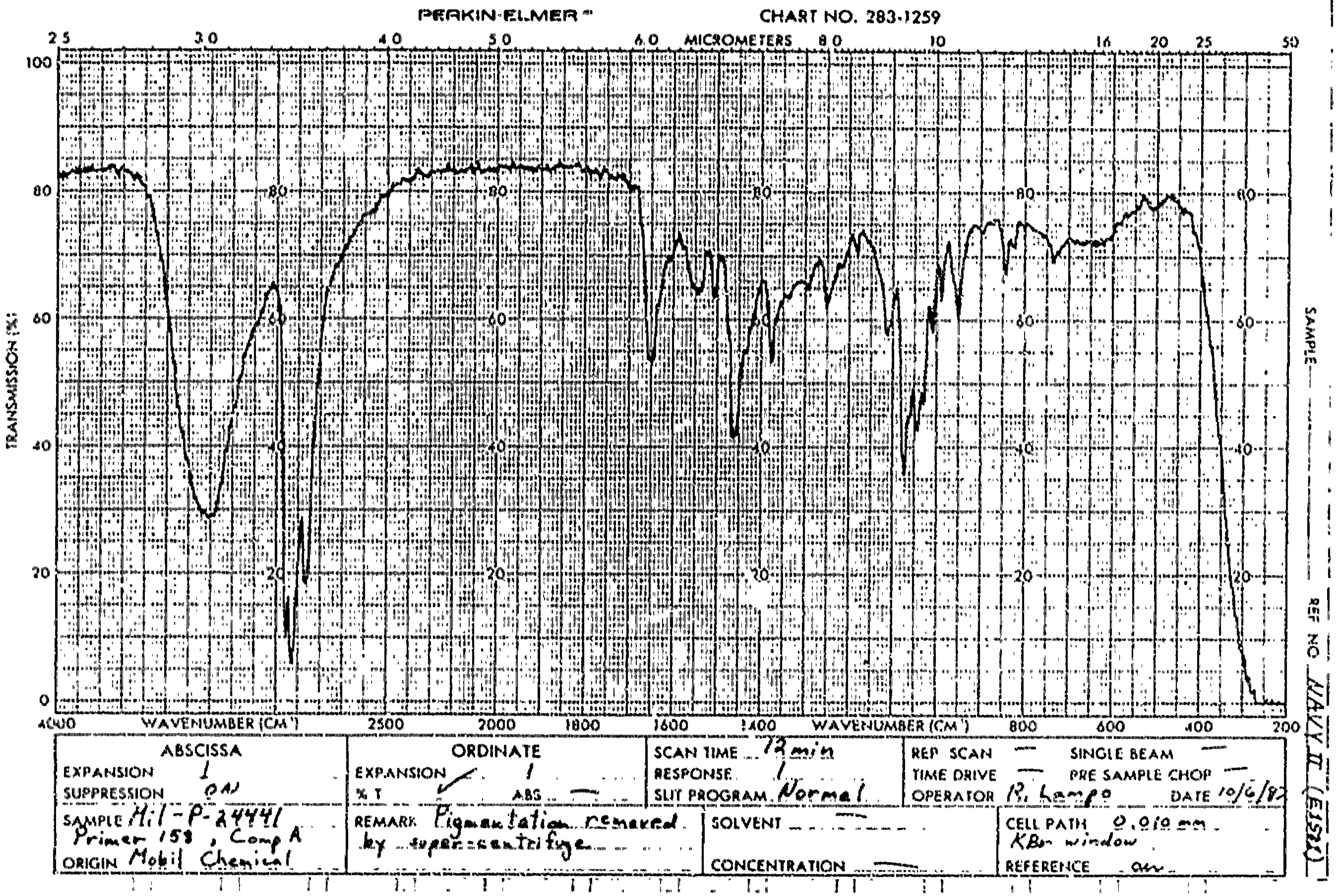
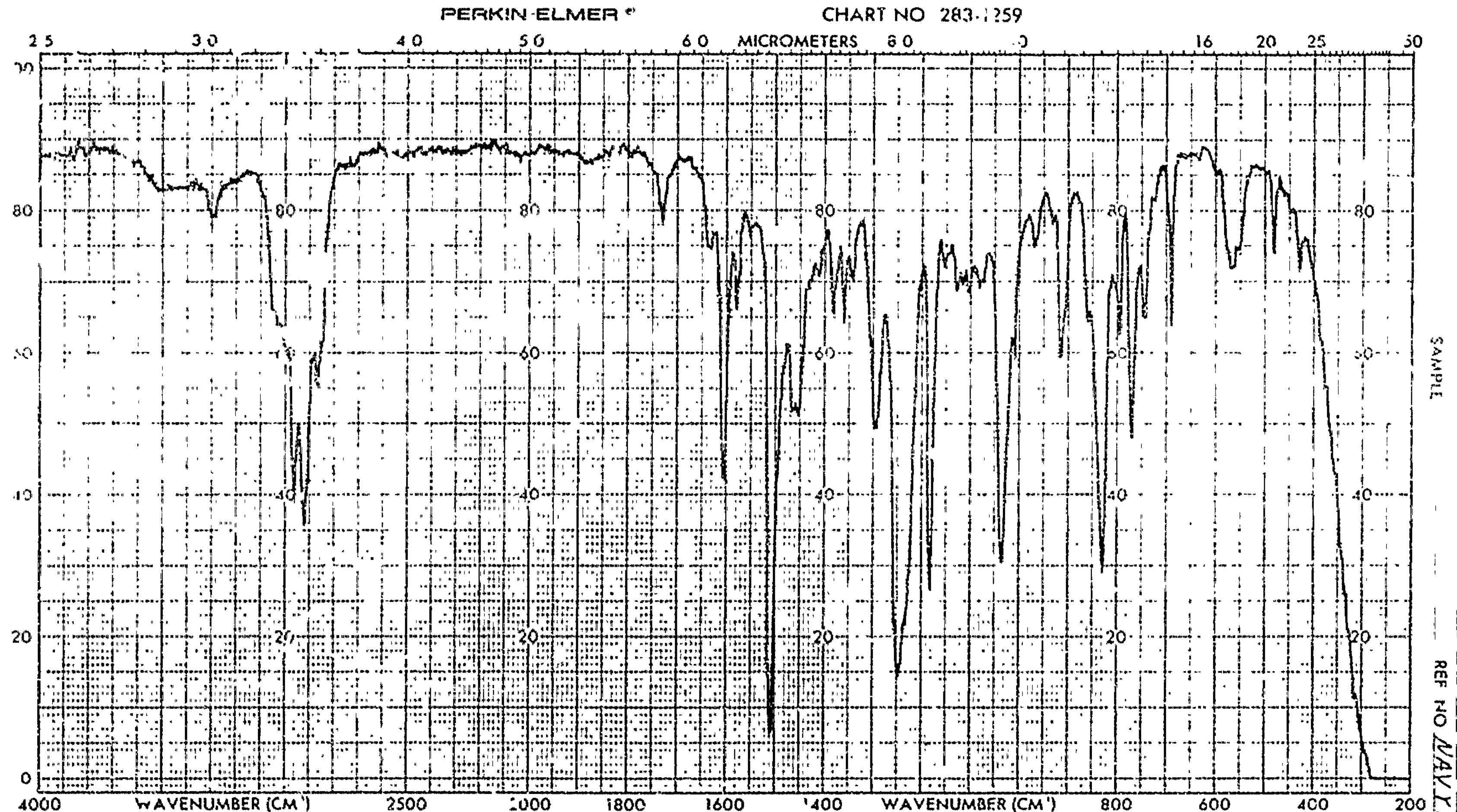


Figure A19. Infrared analysis: MIL-P-24441 primer, component A.



ABSCISSA	ORDINATE	SCAN TIME 12 min	REP. SCAN — SINGLE BEAM —
EXPANSION 1	EXPANSION 1	RESPONSE 1	TIME DRIVE — PRE SAMPLE CHOP —
SUPPRESSION ON	% T ✓ ABS —	SLIT PROGRAM Normal	OPERATOR R. Lampo DATE 10/6/82
SAMPLE Mil-P-24441 Primer 158, Comp B	REMARKS Pigmentation removed by super-centrifuge	SOLVENT —	CELL PATH 0.010 mm KBr window
ORIGIN Mobil Chemical		CONCENTRATION —	REFERENCE air

Figure A20. Infrared analysis: MIL-P-24441 primer, component B.

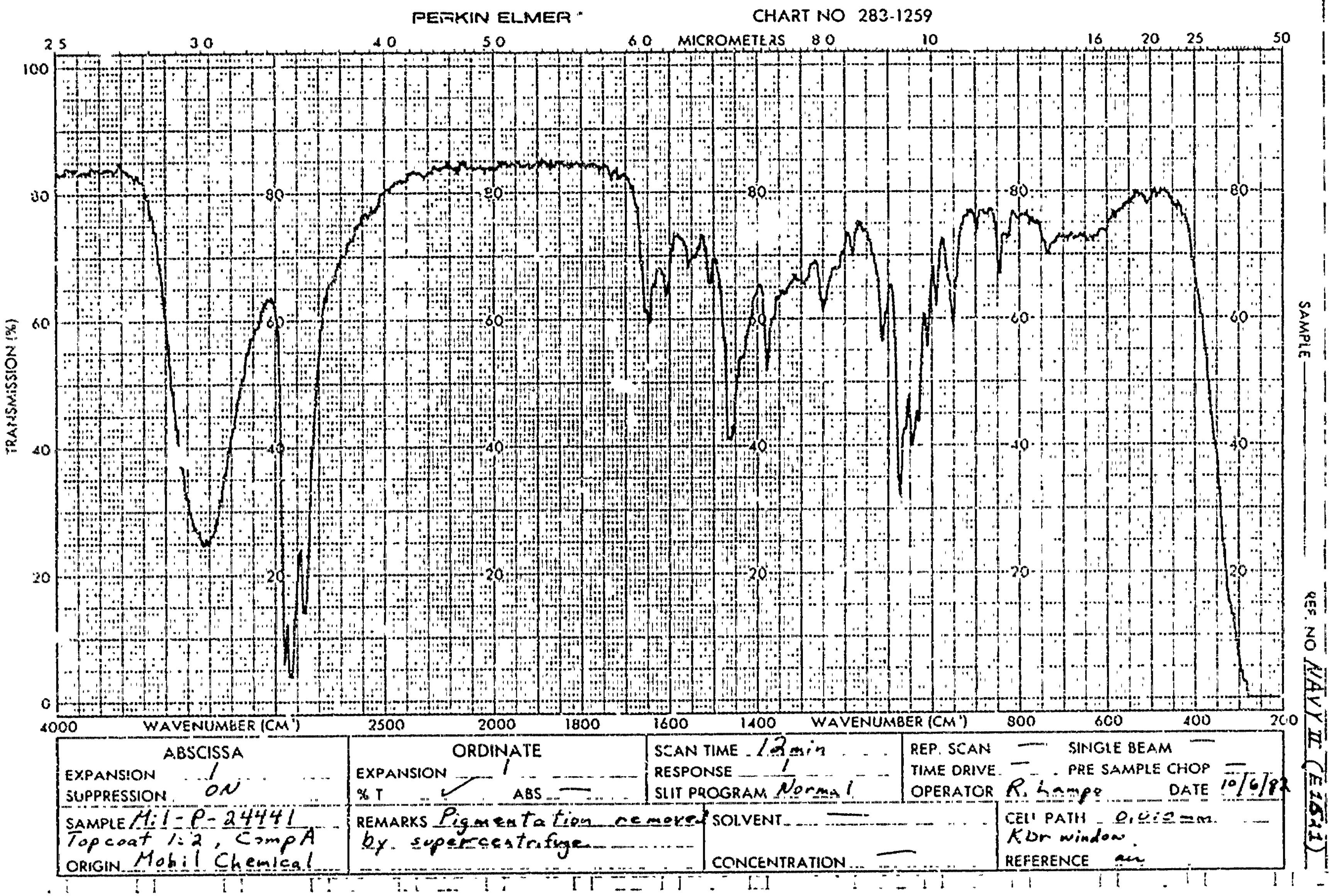


Figure A21. Infrared analysis: MIL-P-24441 topcoat, component A.

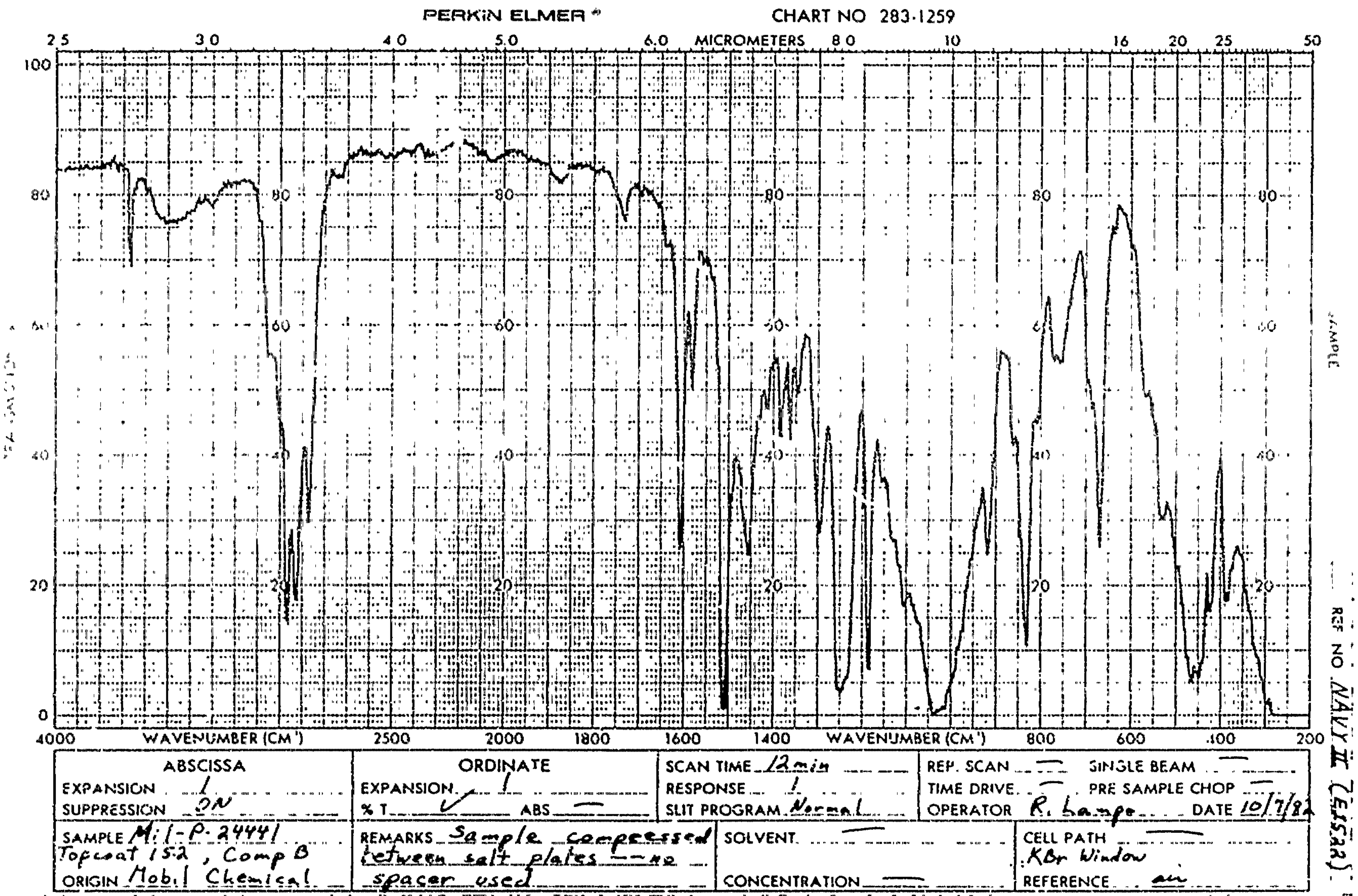


Figure A22. Infrared analysis: MIL-P-24441 topcoat, component B.

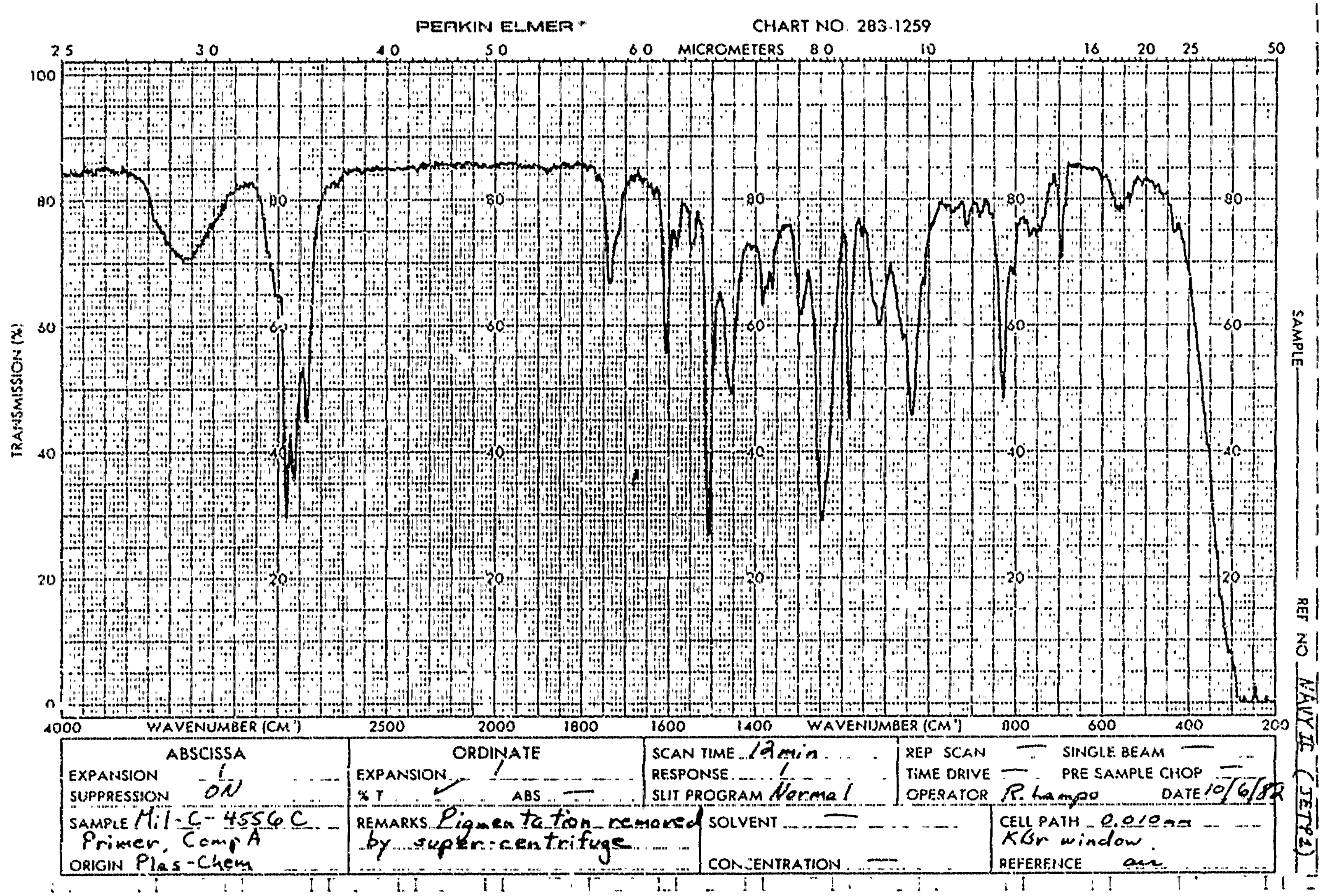


Figure A23. Infrared analysis: MIL-C-4556 primer, component A.

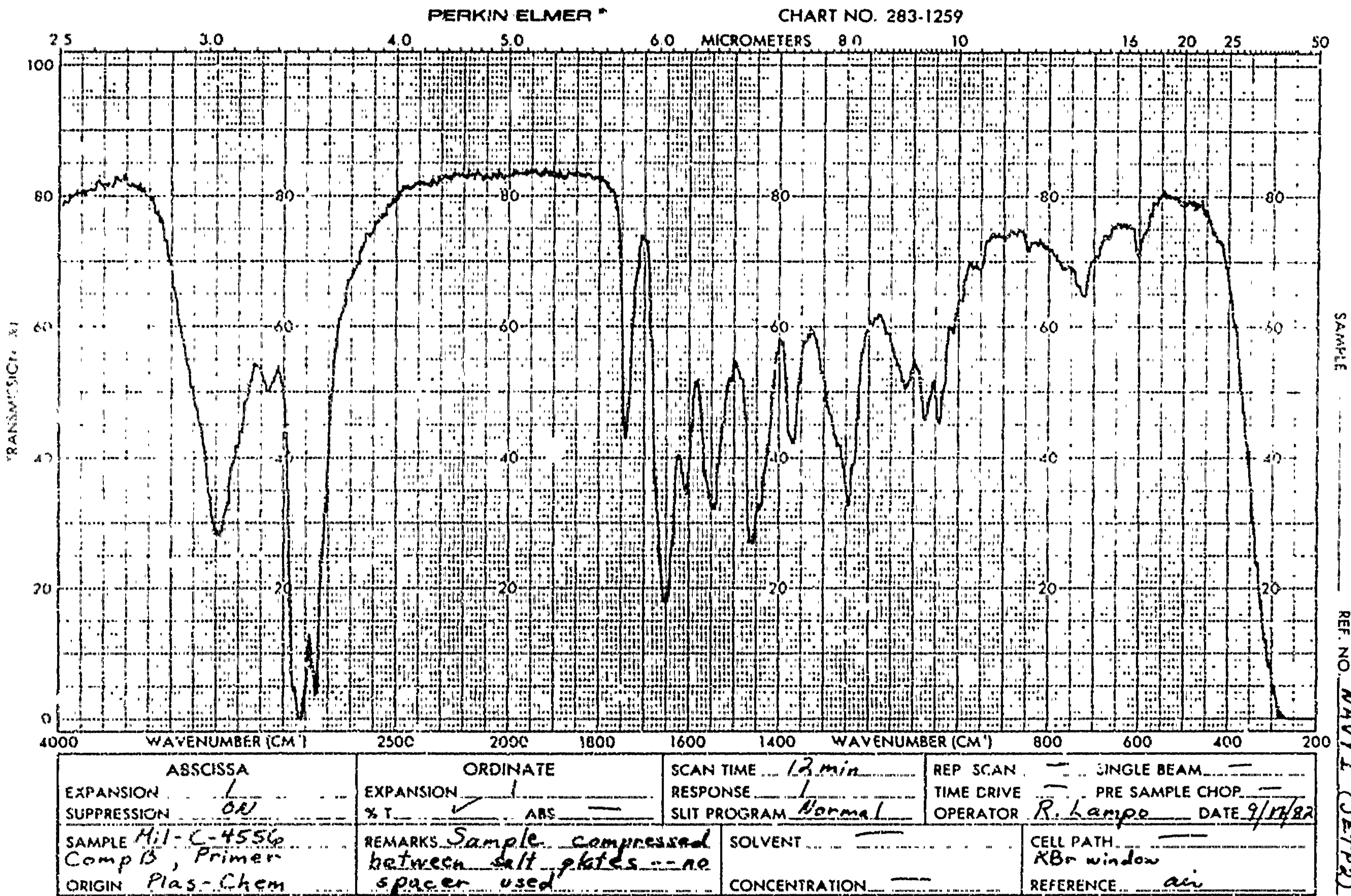


Figure A24. Infrared analysis: MIL-C-4556 primer, component B.

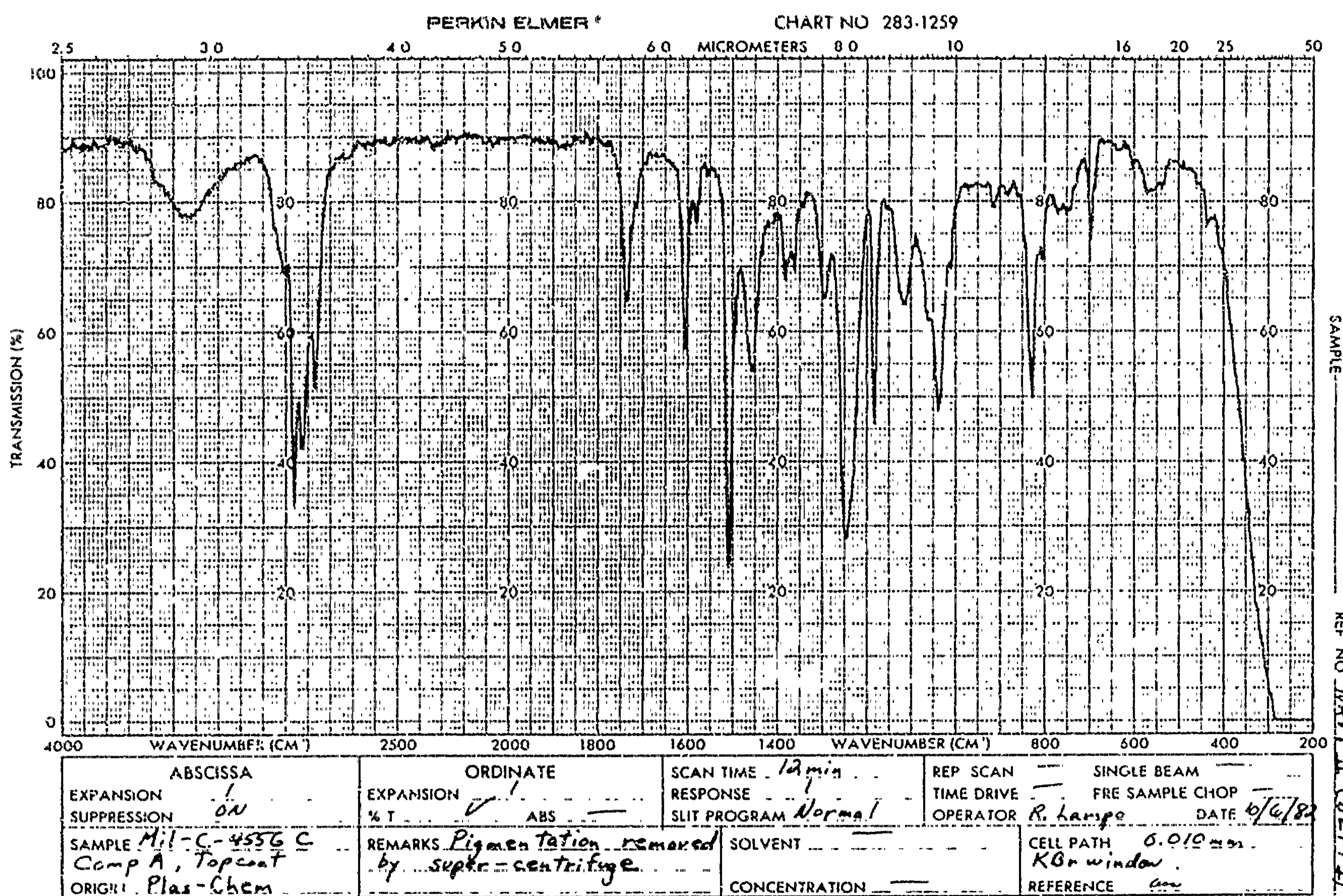
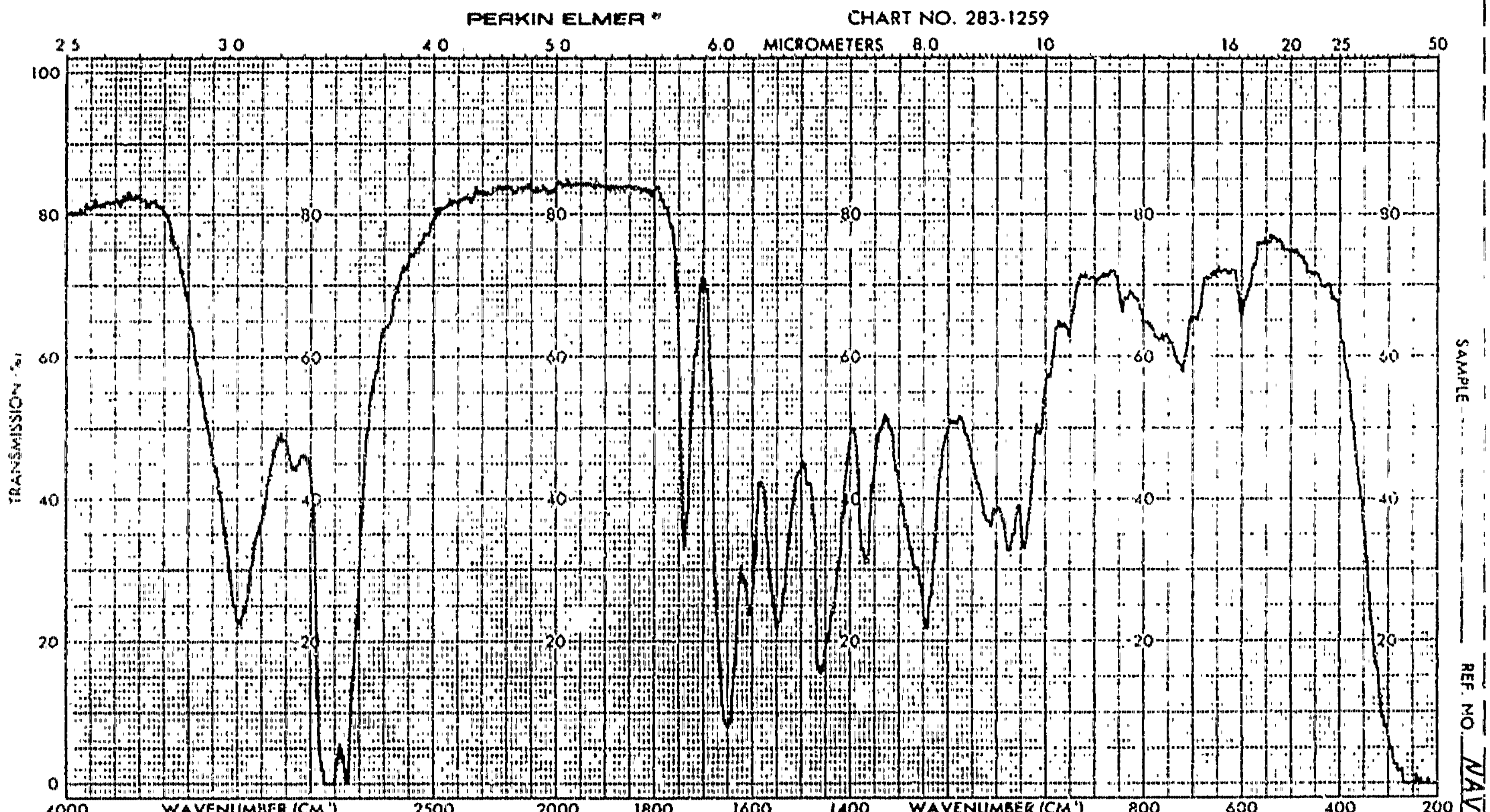


Figure A25. Infrared analysis: MIL-C-4556 topcoat, component A.



ABSCISSA
EXPANSION 1
SUPPRESSION ON

ORDINATE
EXPANSION 1
% T ✓ ABS —

SCAN TIME 12 min
RESPONSE 1
SLIT PROGRAM Normal

REP SCAN — SINGLE BEAM —
TIME DRIVE — PRE SAMPLE CHOP —
OPERATOR R. Lampo DATE 9/15/82

SAMPLE Mil-C-4556 CompB, Topcoat
ORIGIN Plas-Chem

REMARKS Sample compressed between salt plates -- no spacer used.

SOLVENT —
CONCENTRATION —

CELL PATH — KBr window
REFERENCE air

Figure A26. Infrared analysis: MIL-C-4556 topcoat, component B.

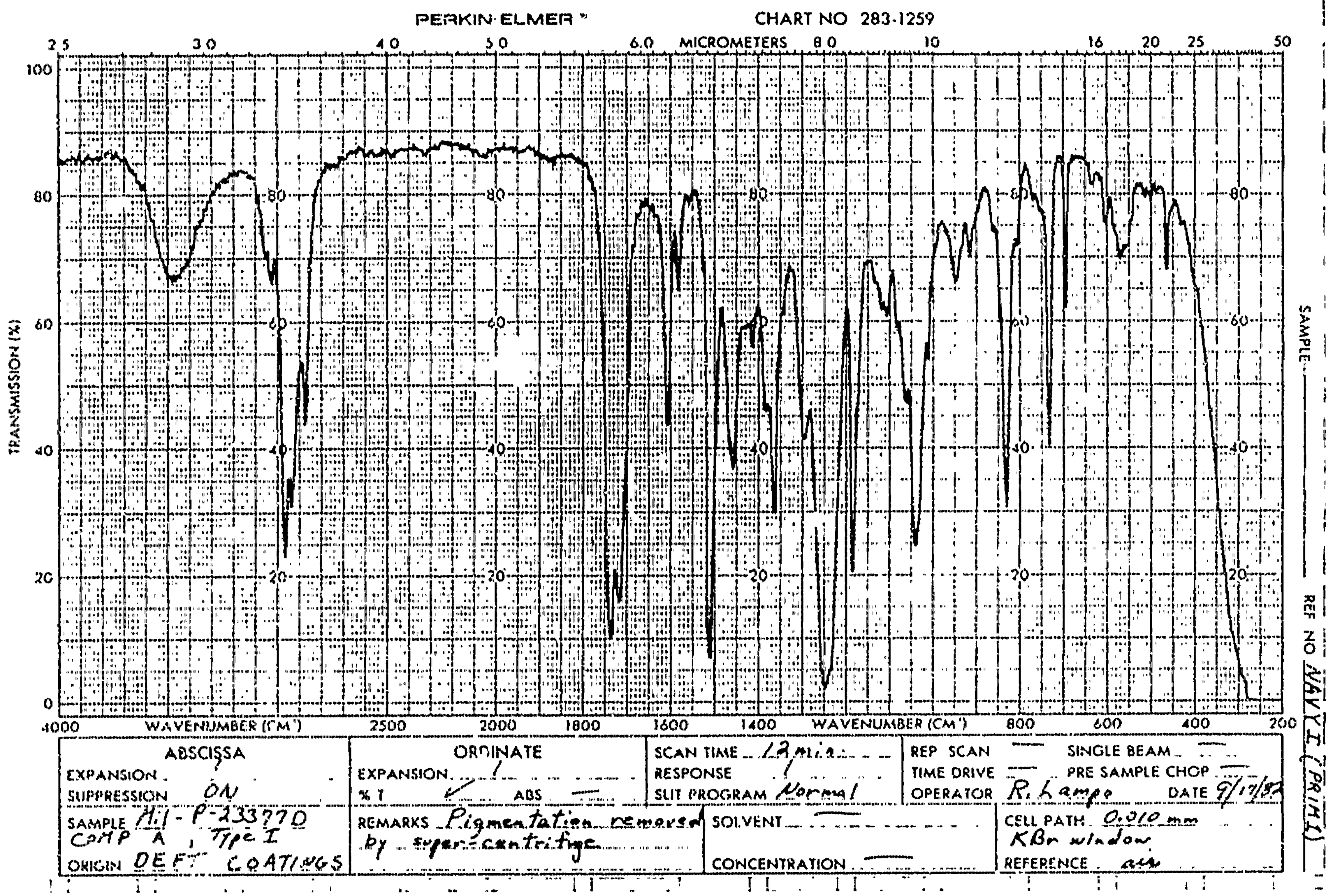


Figure A27. Infrared analysis: MIL-P-23377, component A.

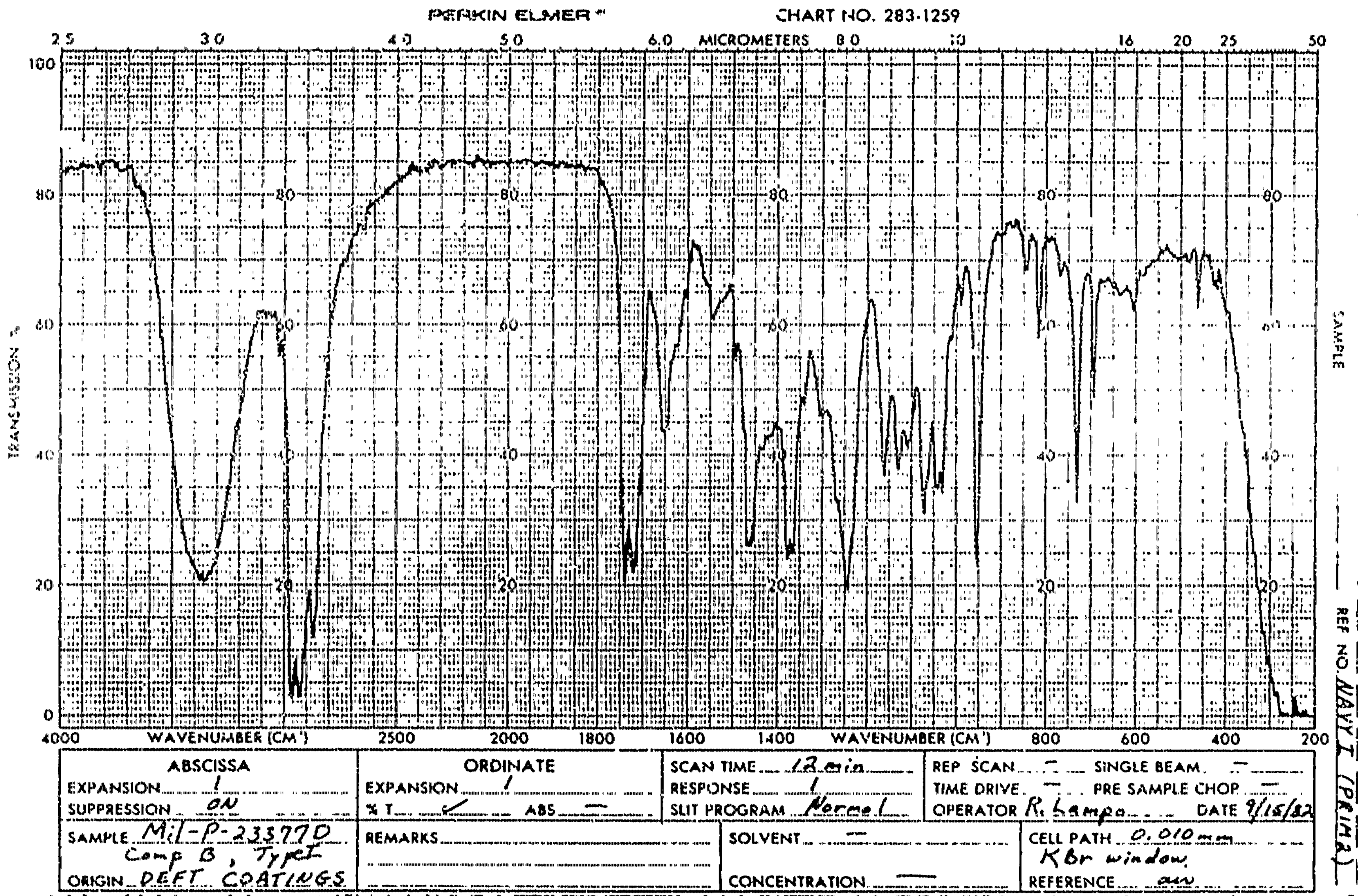


Figure A28. Infrared analysis: MIL-P-23377, component B.

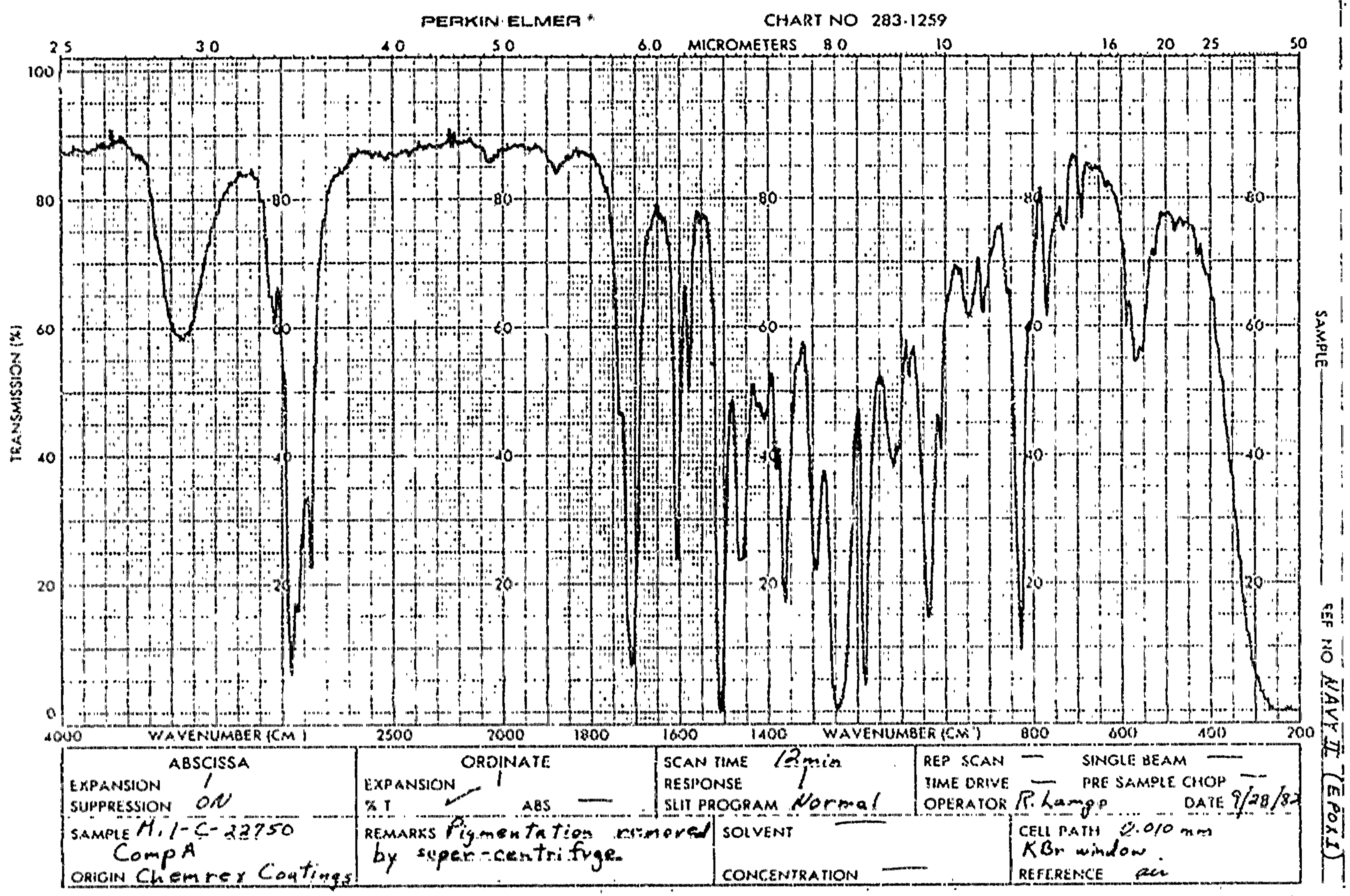


Figure A29. Infrared analysis: MIL-C-22750, component A.

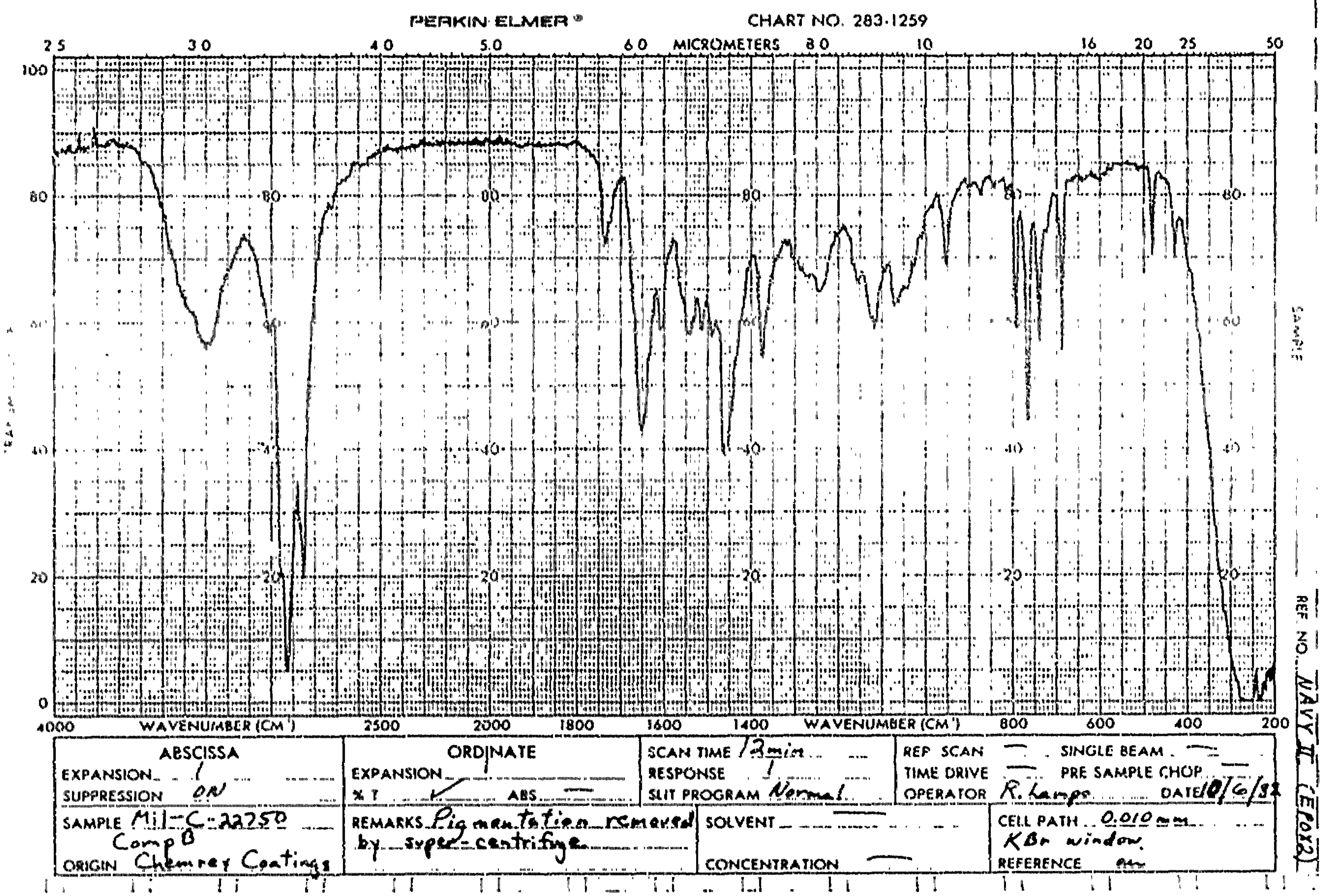


Figure A30. Infrared analysis: MIL-C-22750, component B.

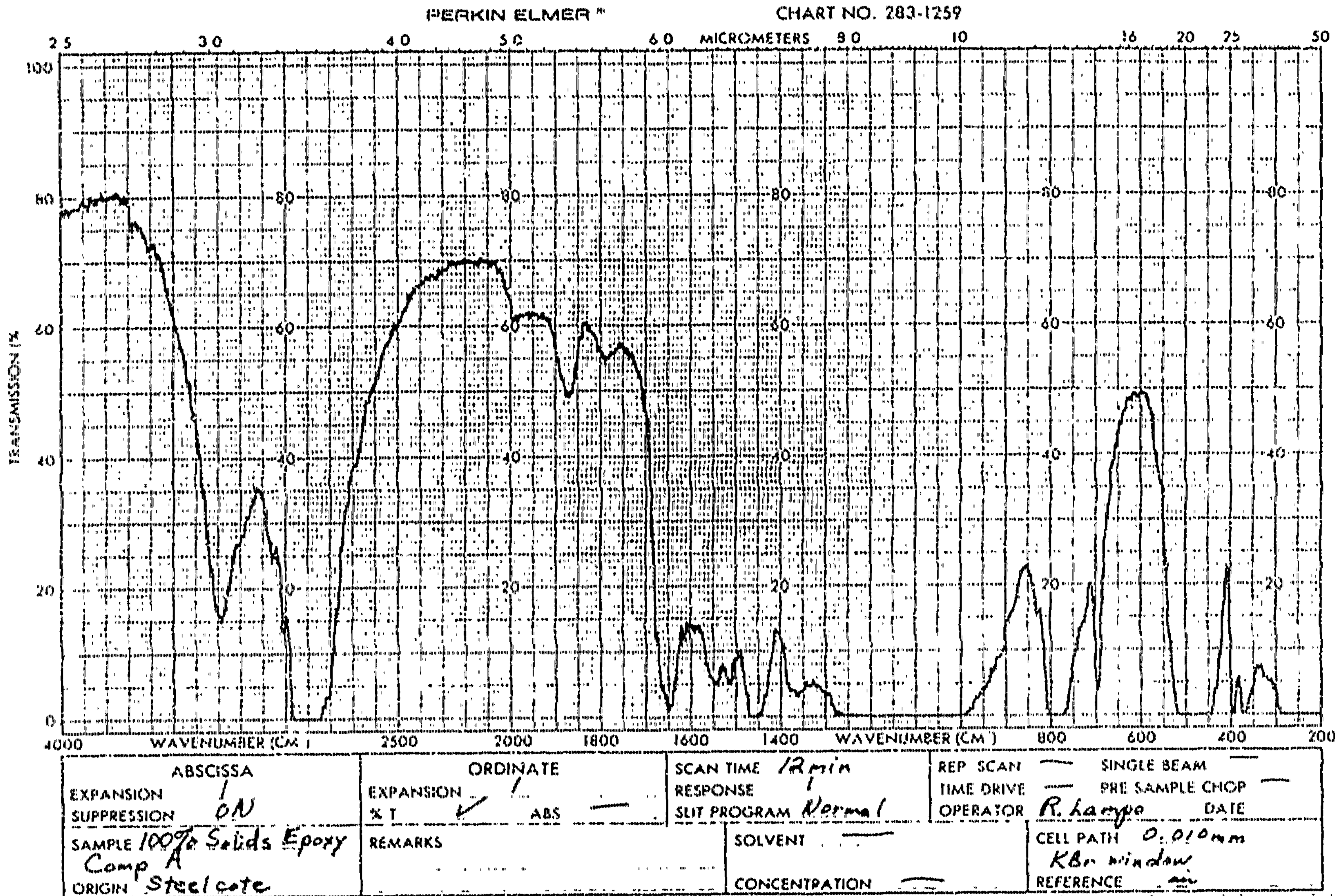


Figure A31. Infrared analysis: Steelcote 100 percent solids epoxy, component A.

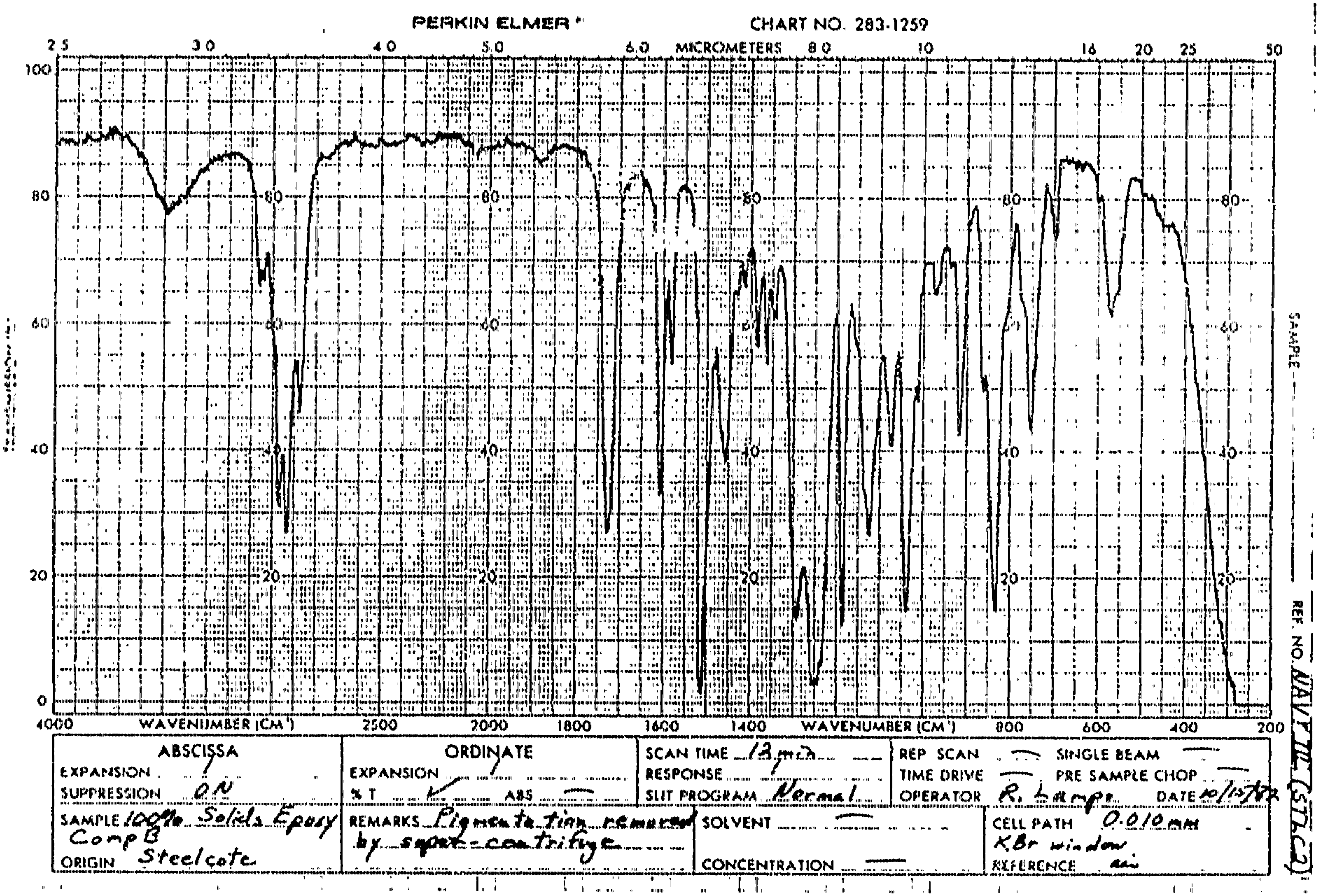


Figure A32. Infrared analysis: Steelcote 100 percent solids epoxy, component B.

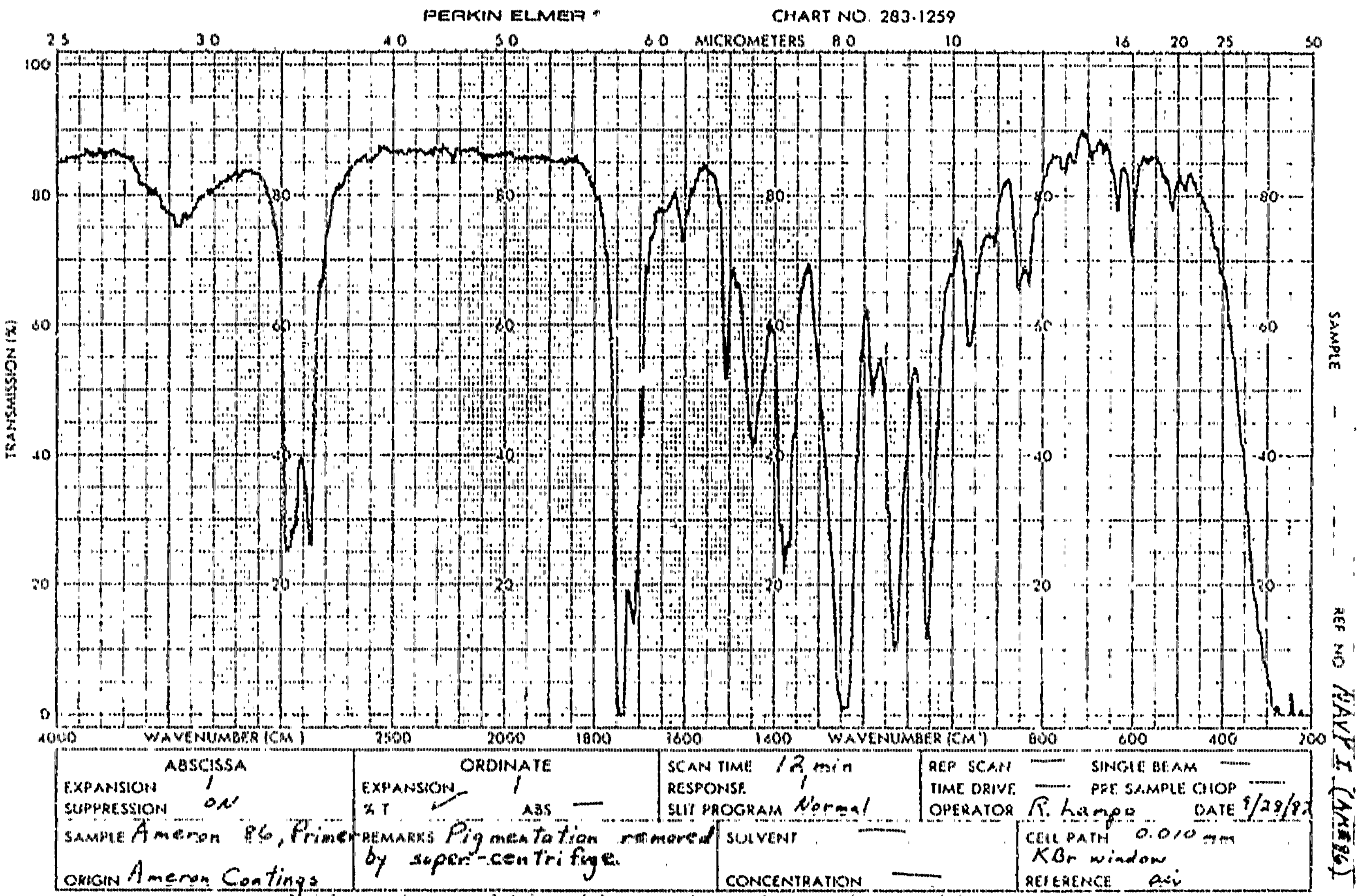


Figure A33. Infrared analysis: Amercoat 86, liquid, pigment removed.

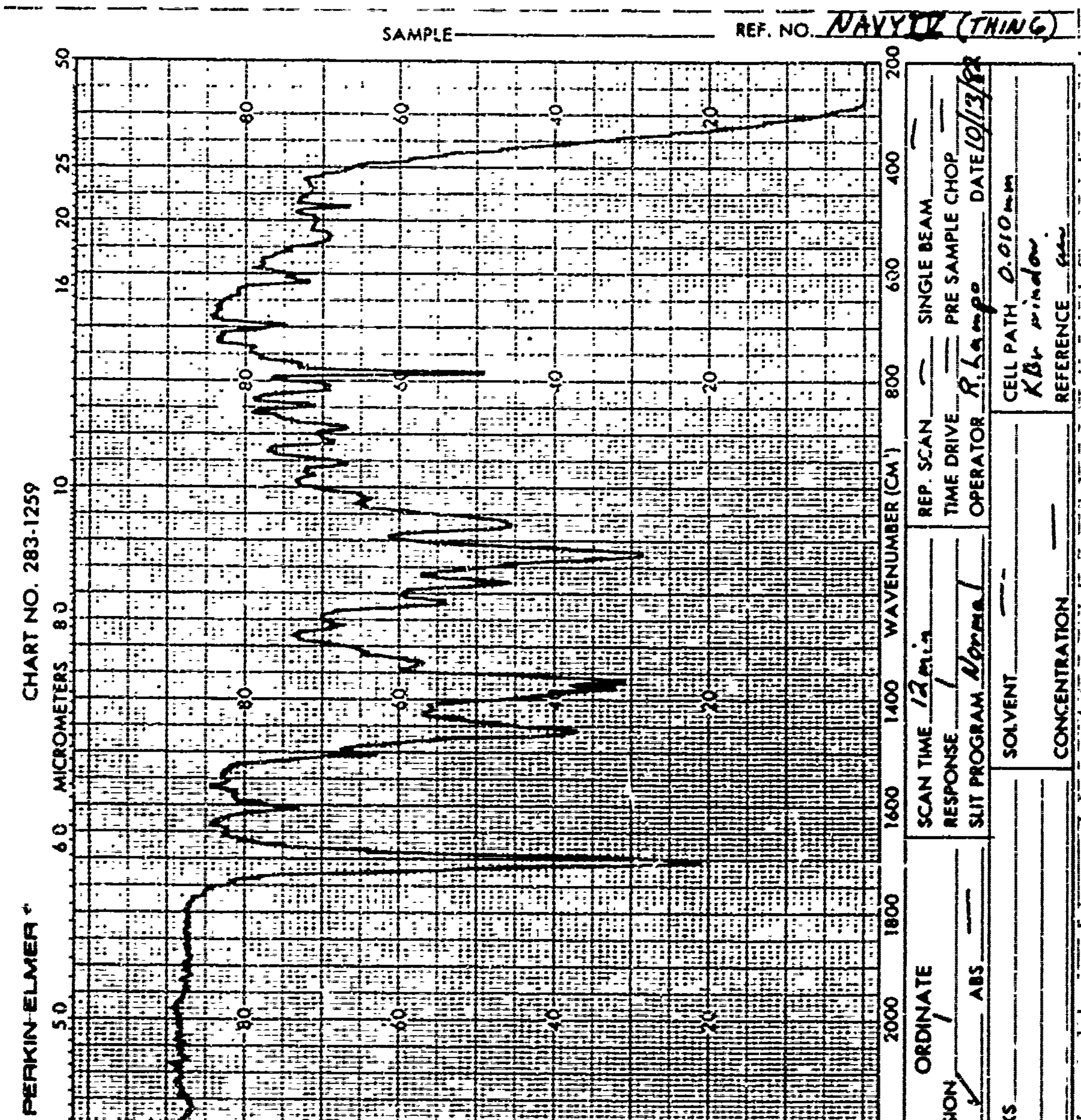


Figure A34. Infrared analysis: Amercoat 6 thinner.

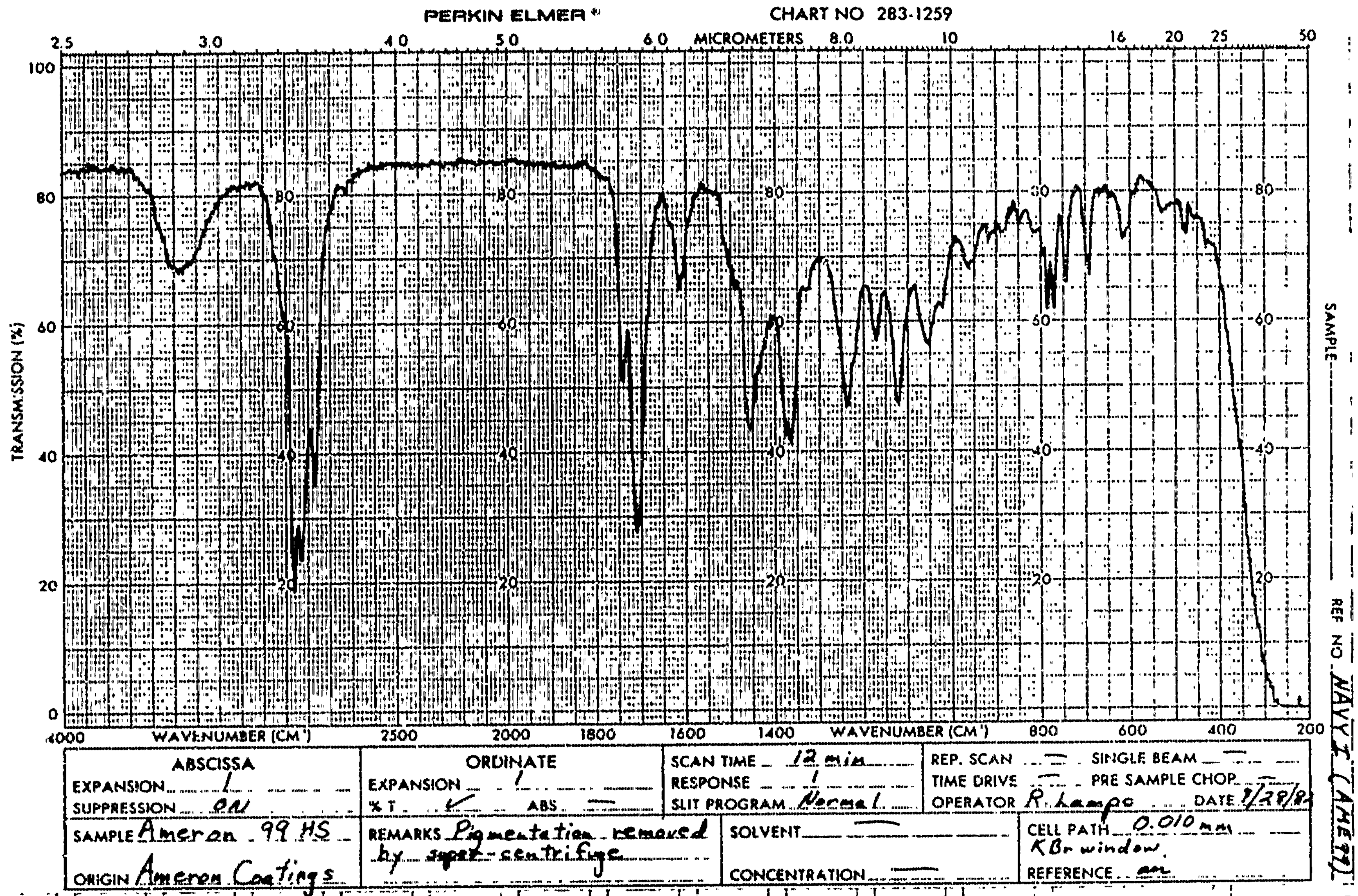


Figure A35. Infrared analysis: Amercoat 99HS, liquid, pigment removed.

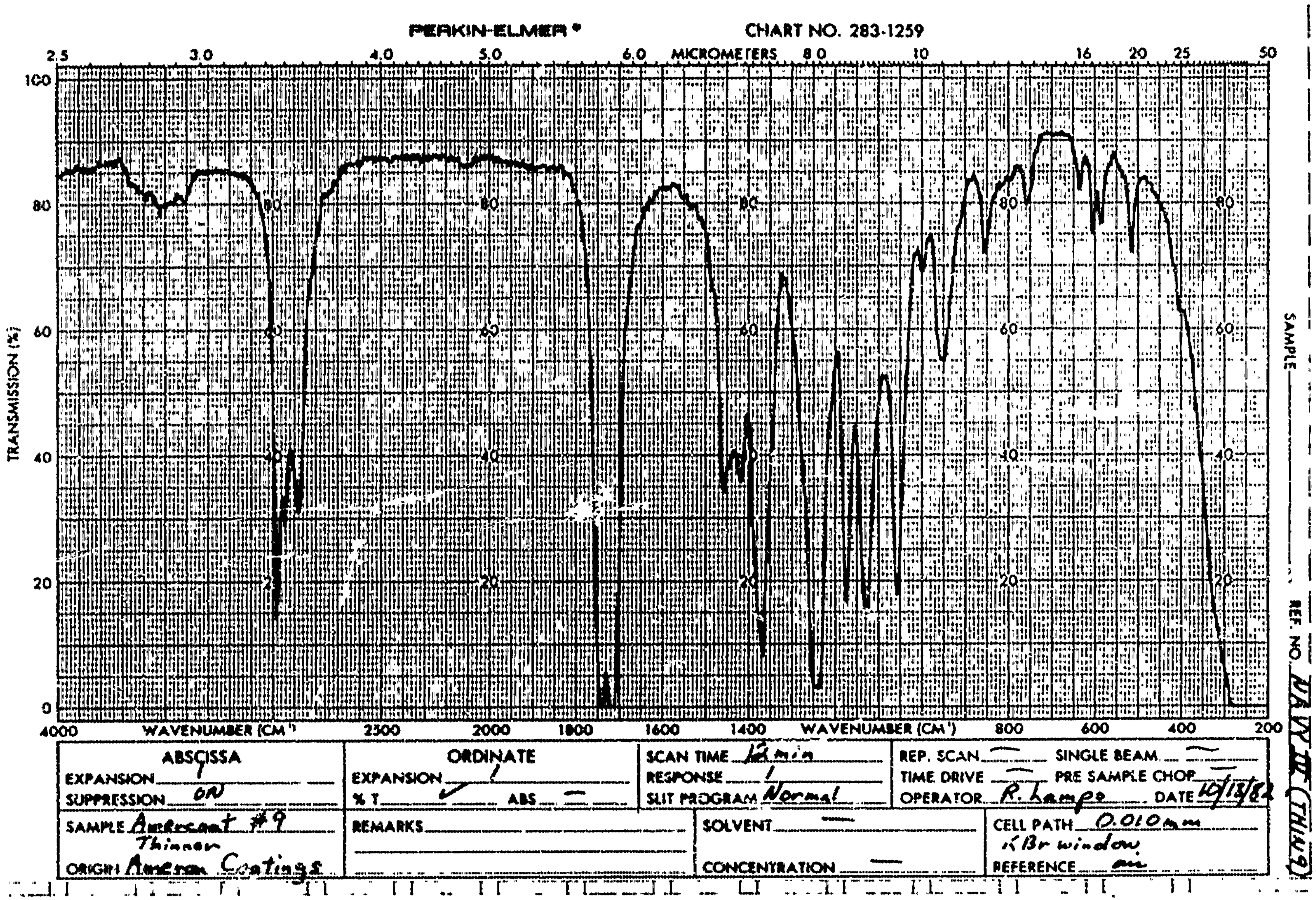


Figure A36. Infrared analysis: Amercoat 9 thinner.

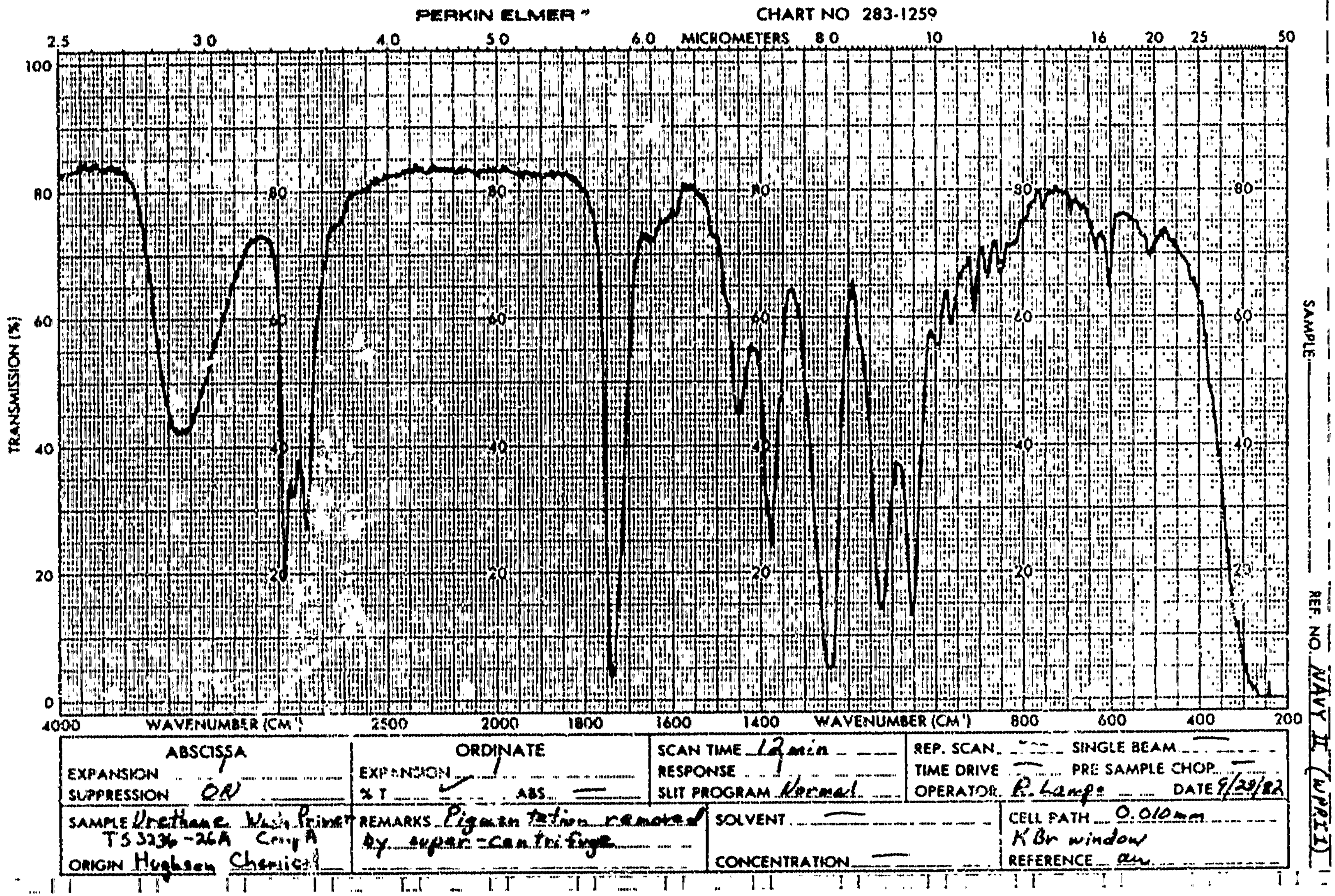


Figure A37. Infrared analysis: Hughson TS 3236-26 wash primer, component A.

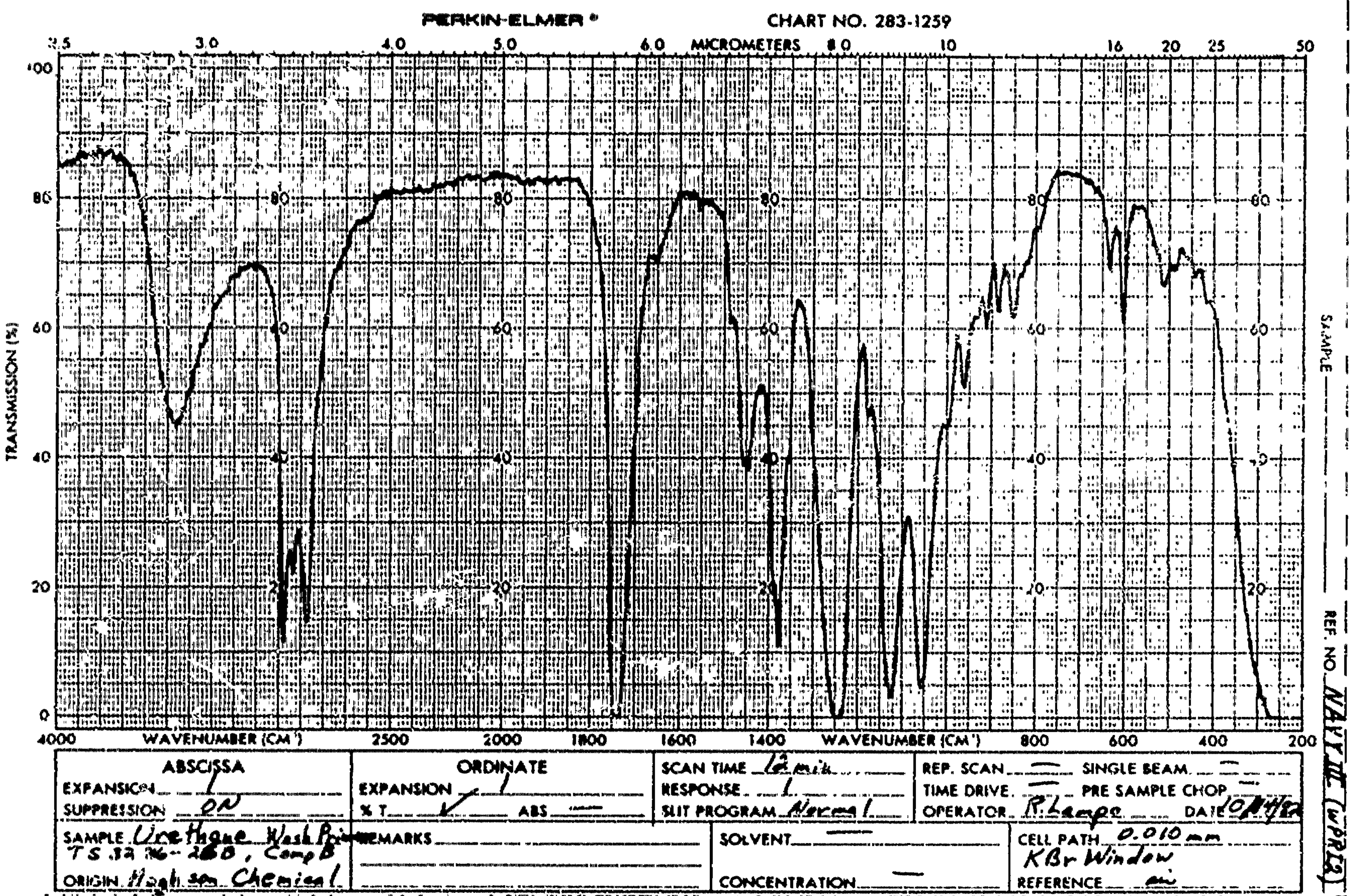


Figure A38. Infrared analysis: Hughson TS 3236-26 wash primer, component B.

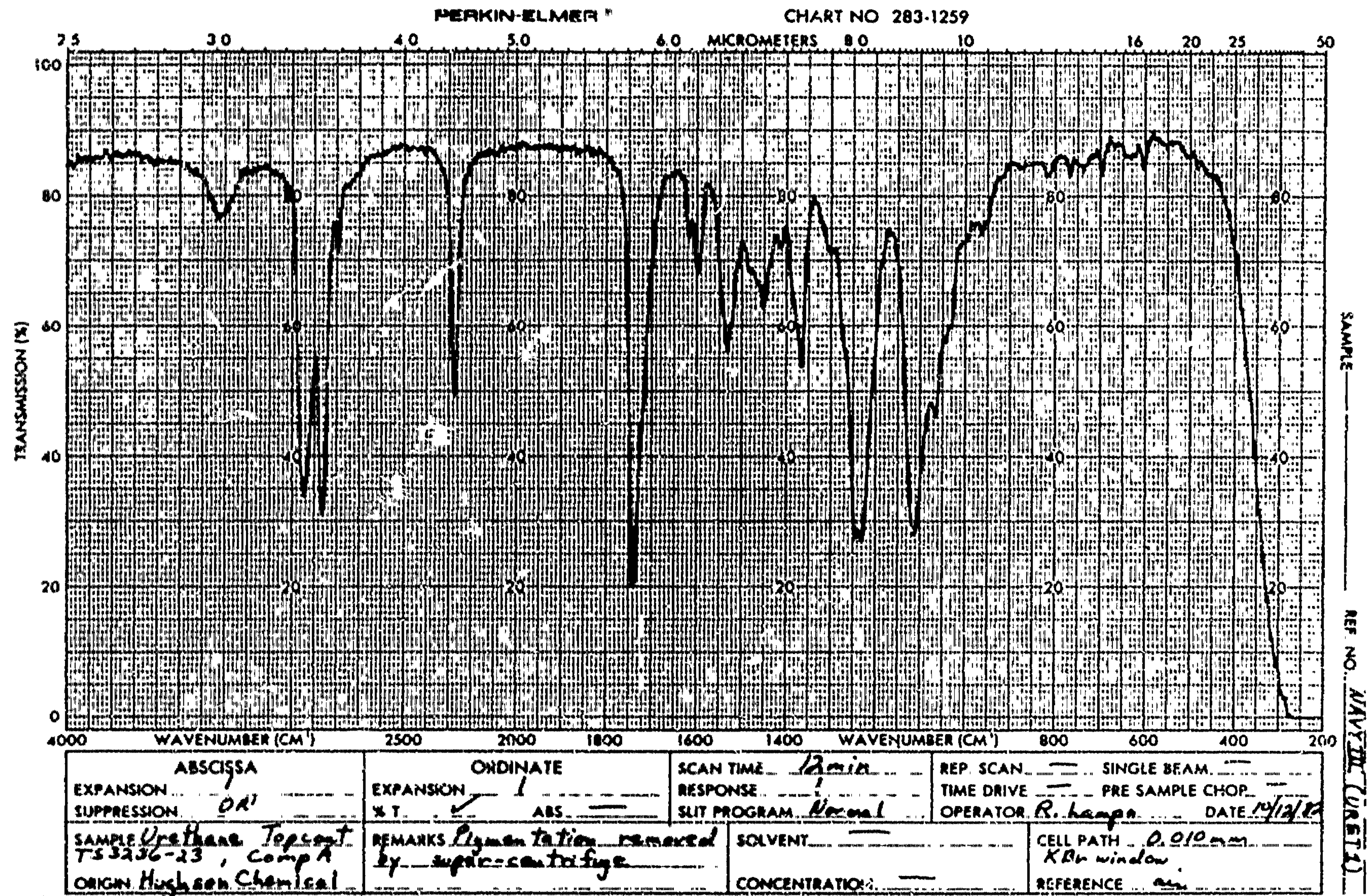


Figure A39. Infrared analysis: Hughson TS 3236-23 topcoat, component A.

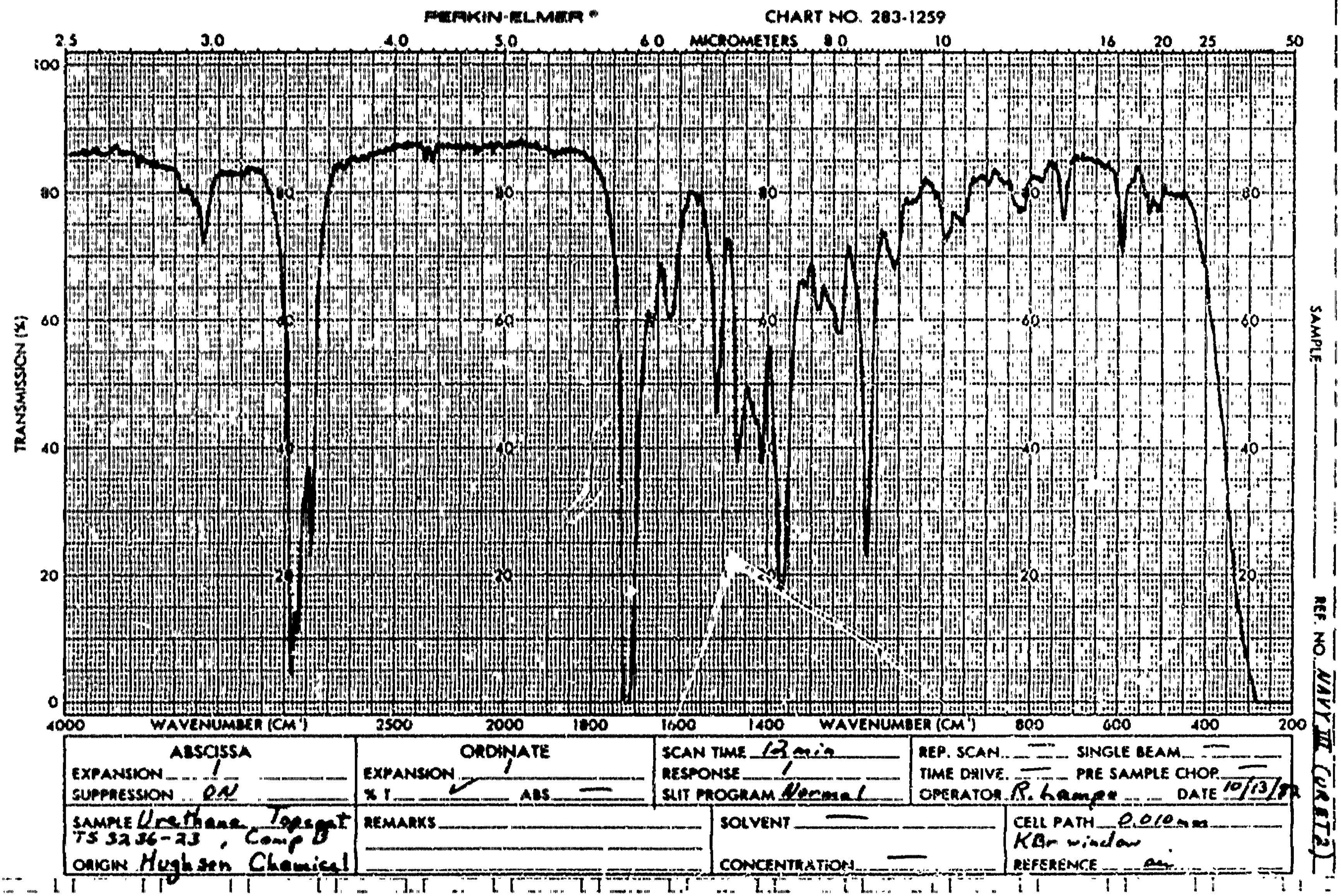


Figure A40. Infrared analysis: Hughson TS 3236-23 topcoat, component B.

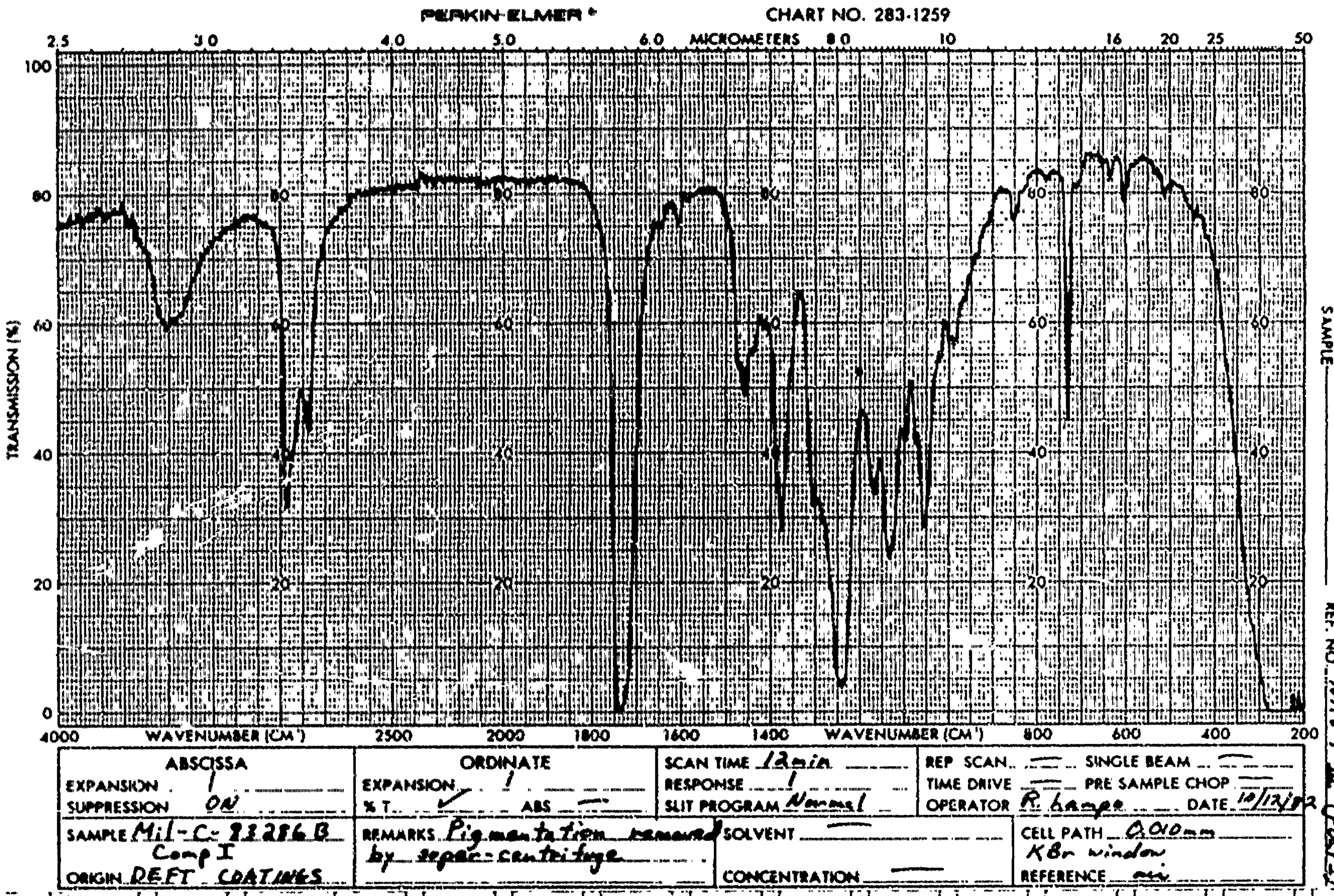


Figure A41. Infrared analysis: MIL-C-83286, component I.

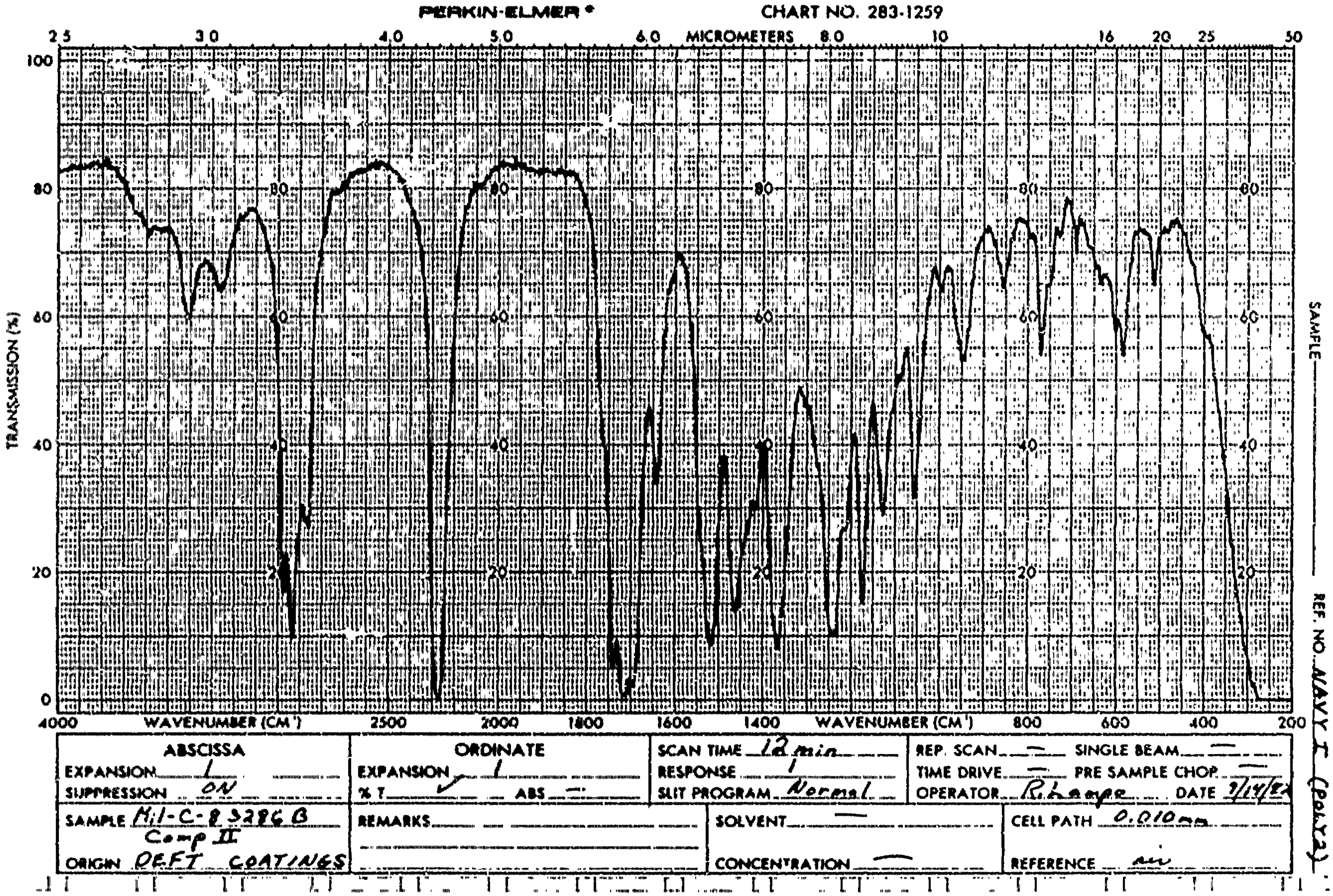


Figure A42. Infrared analysis: MIL-C-83286, component II.

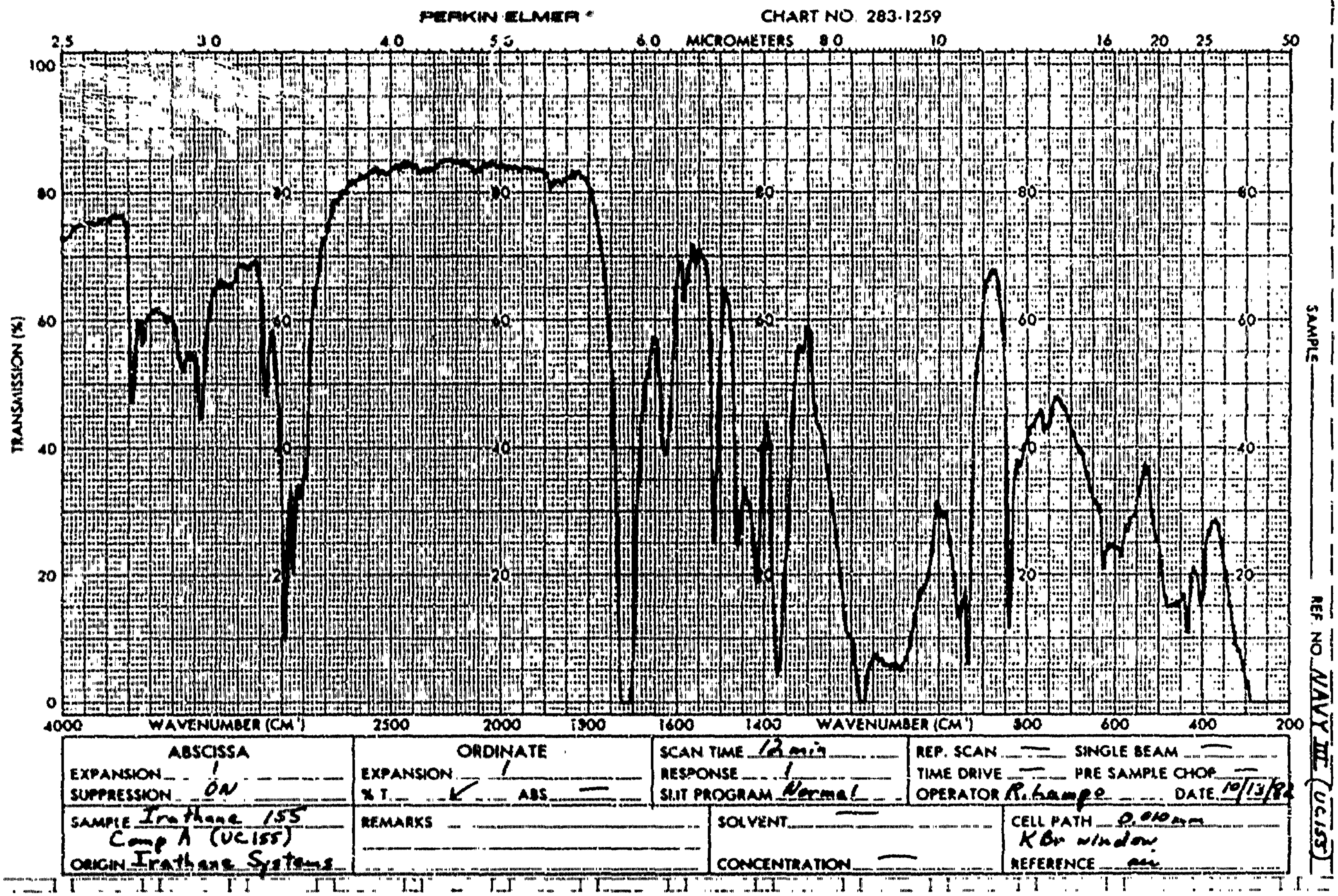


Figure A43. Infrared analysis: Irathane 155, component A.

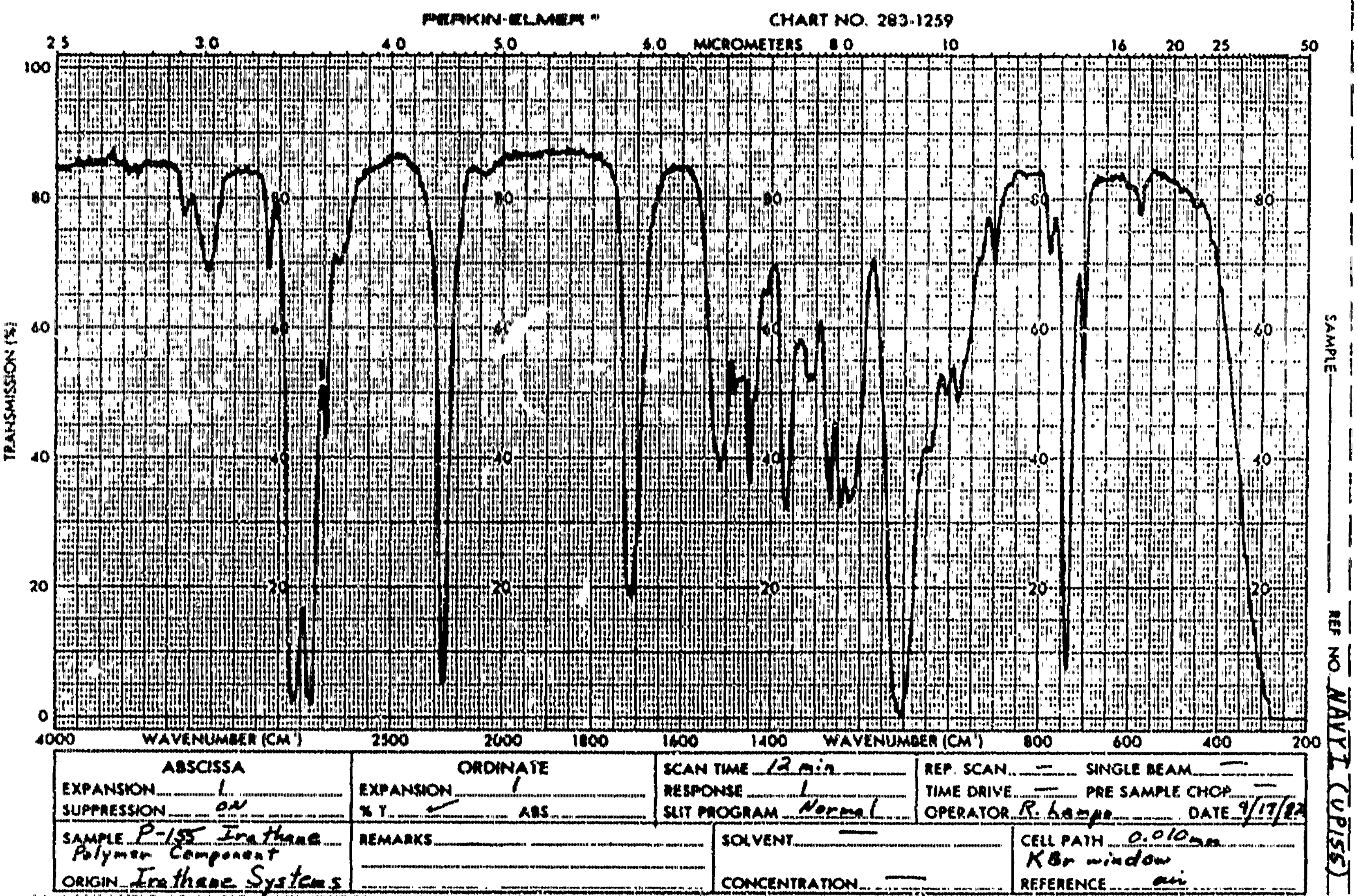


Figure A44. Infrared analysis: Irathane 155, component B.

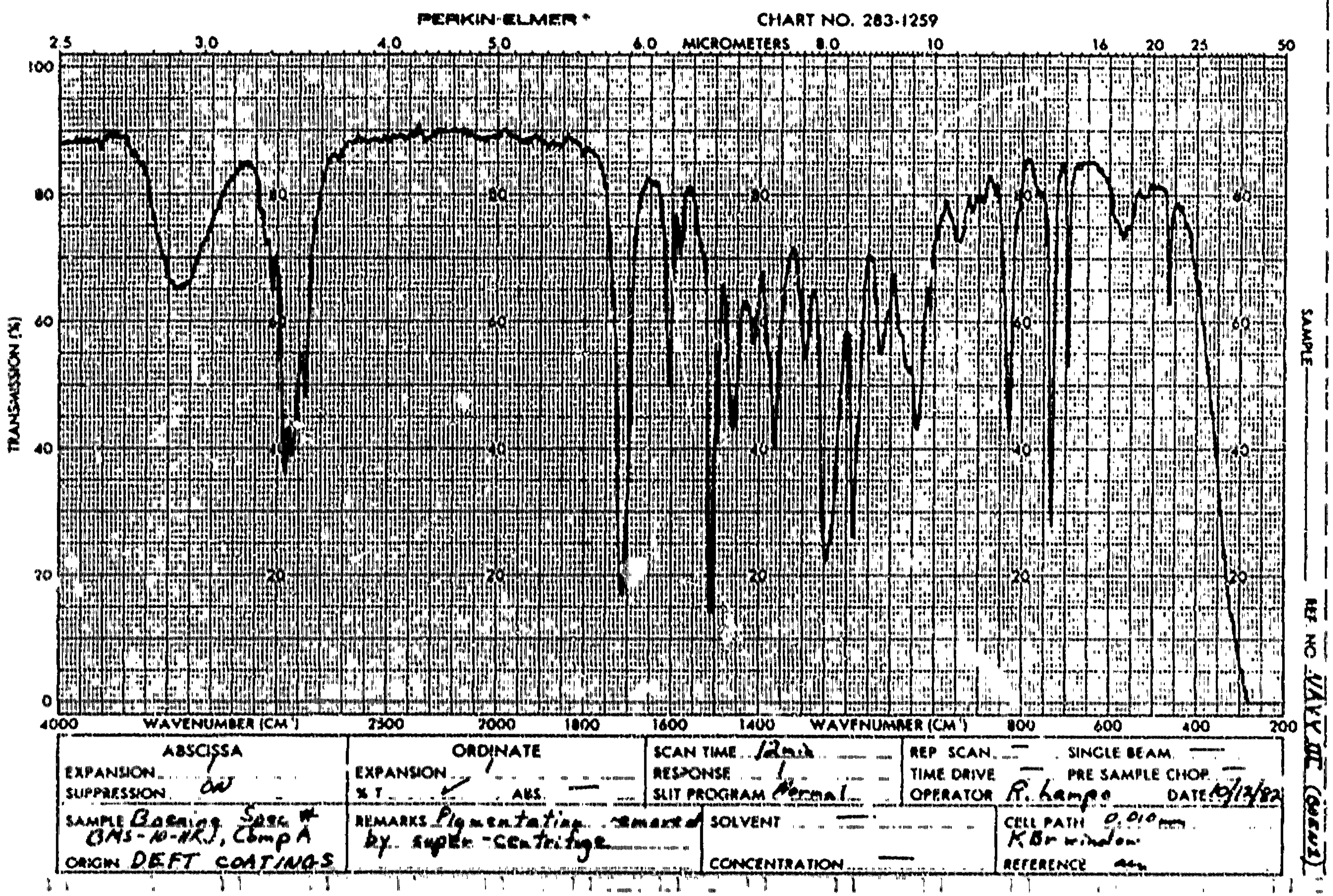


Figure A45. Infrared analysis: BMS-10-11K, component A.

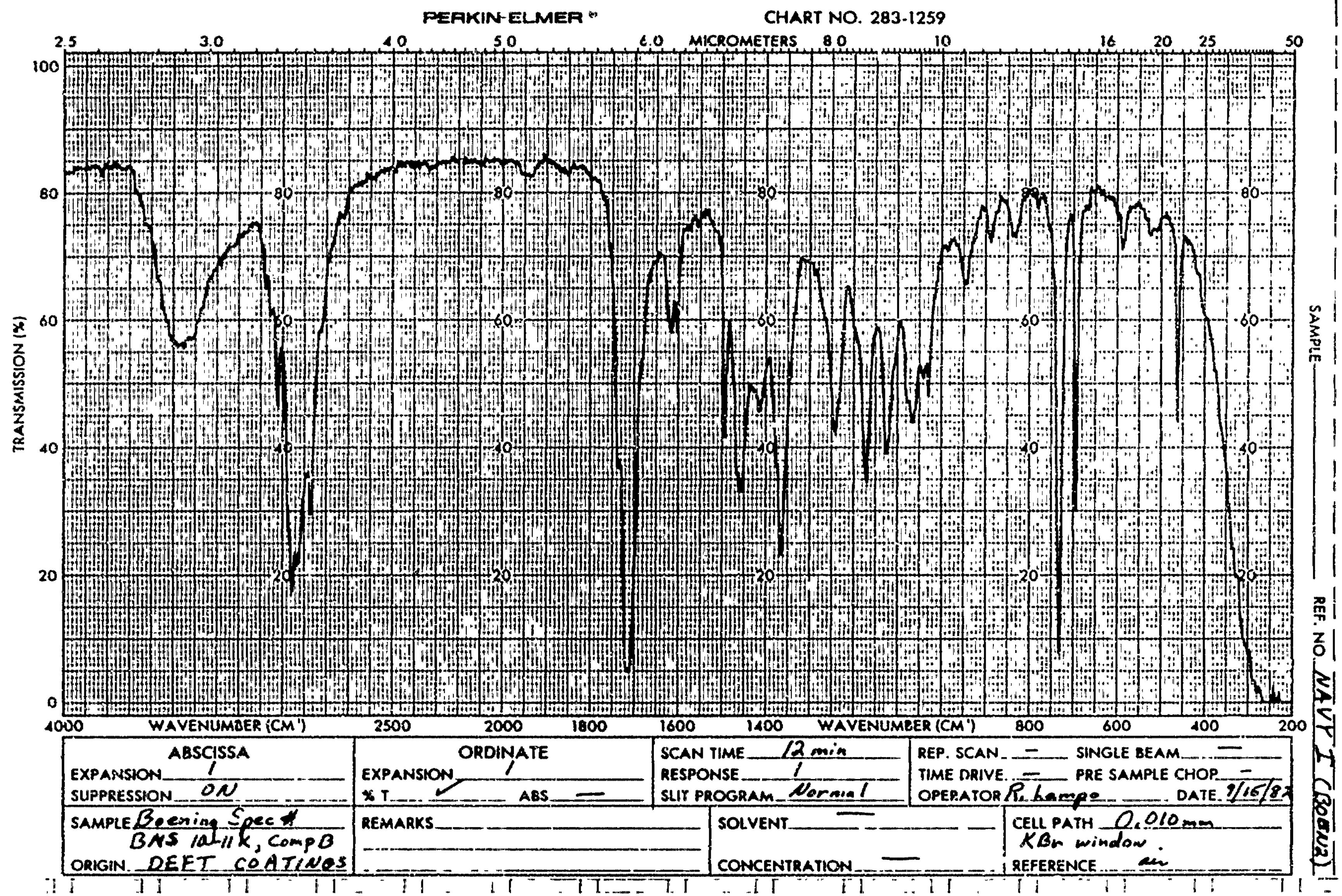


Figure A46. Infrared analysis: BMS-10-11K, component B.

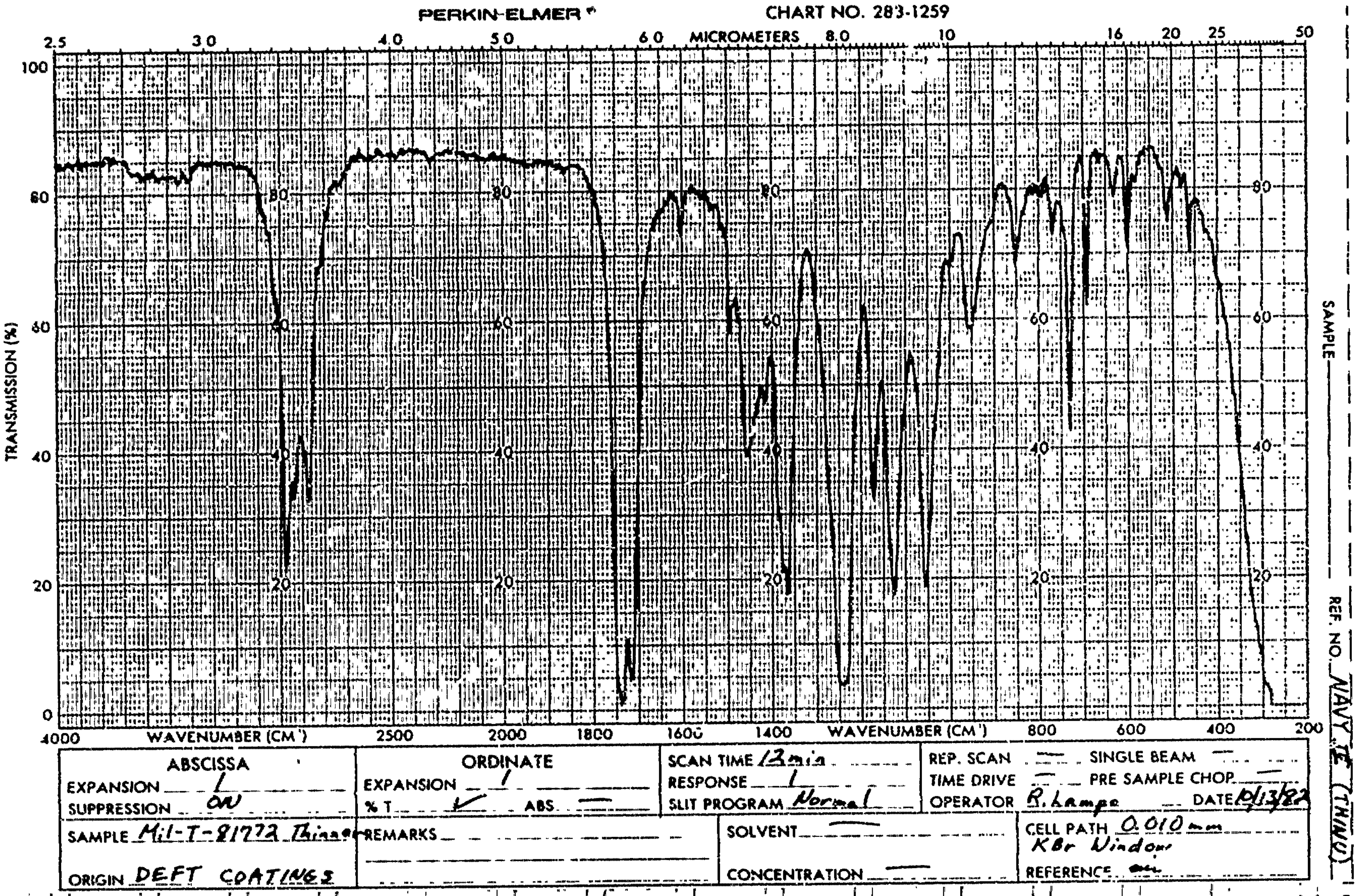


Figure A47. Infrared analysis: MIL-T-81772/AS thinner.

APPENDIX B:

ADDITIONAL VENDOR INFORMATION

MATERIAL SAFETY DATA SHEET

FOR COATINGS, RESINS AND RELATED MATERIALS

GSF

(Approved by U.S. Department of Labor "Essentially Similar" to Form OSHA-20)

Section I

MANUFACTURER'S NAME Mobile Paint Mfg. Co., Inc.

DATE OF PREP 02/16/83

STREET ADDRESS P. O. Box 717

CITY, STATE, AND ZIP CODE Theodore, AL. 36590

EMERGENCY TELEPHONE NO (205) 653-0110

PRODUCT CLASS Catalyst

INFORMATION TELEPHONE NO (205) 653-0110

MANUFACTURERS CODE IDENTIFICATION 35-EF-51

TRADE NAME MIL-P-24441/2A, 3A, 4A, 5A, 6A Component B

Section II—HAZARDOUS INGREDIENTS

INGREDIENT	C.A.S. NO.	PERCENT BY WT.	TLV-TWA PPM	TLV-TWA Mg/M3	VAPOR PRESSURE
Super Hi Flash Naphtha	64742-94-5	24.8	35	NA*	3.0
*Not applicable					

ection III—PHYSICAL DATA

BOILING RANGE 315-400°F

VAPOR DENSITY [X] HEAVIER [ ] LIGHTER THAN AIR

EVAPORATION RATE [ ] FASTER [X] SLOWER THAN ETHER

PERCENT VOLATILE BY VOLUME 34.7

WEIGHT PER GALLON 10.17

Section IV—FIRE AND EXPLOSION HAZARD DATA

FLAMMABILITY CLASSIFICATION OSHA Combustible Liquid Class II

FLASH POINT °F 120°C (SETAFLASH)

LEL 0.5

EXTINGUISHING MEDIA

[X] FOAM [X] "ALCOHOL" FOAM [X] CO_2 [X] DRY CHEMICAL [ ] WATER FOG [ ] OTHER

UNUSUAL FIRE AND EXPLOSION HAZARDS During emergency conditions overexposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent. Obtain medical attention. Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions.

Full protective equipment including self-contained breathing apparatus should be used. Water spray may be ineffective. If water is used, fog nozzles are preferable. Water may be used to cool closed containers to prevent pressure build-up and possible autoignition or explosion when exposed to extreme heat.

Figure B1. Vendor information: MIL-P-24441.

Section V—HEALTH HAZARD DATA 35-EF-51

EFFECTS OF OVEREXPOSURE

Inhalation: Anesthetic. Excessive inhalation can cause irritation of the respiratory tract, or acute nervous system depression characterized by the following progressive steps: Headache, dizziness, staggering gait, confusion, unconsciousness, coma and even asphyxiation.

Skin Contact: Moderate irritation, defatting, dermatitis. May be a sensitizer in some individuals.

Eye Contact: Severe irritation, redness, tearing, blurred vision. May be a sensitizer in some individuals.

Ingestion: Gastrointestinal irritation, nausea, vomiting, and diarrhea.

EMERGENCY AND FIRST AID PROCEDURES Inhalation: Remove to fresh air. Administer oxygen if breathing is difficult. Restore breathing if necessary. Treat symptomatically. Consult a physician.

Splash (skin): Wash affected areas with soap and water. Remove and launder contaminated clothing. Consult a physician if irritation persists.

Splash (eyes): Flush immediately with large amounts of water for at least 15 minutes. Take to a physician for medical treatment.

Ingestion: Drink 1 or 2 glasses of water to dilute. Do not induce vomiting. Aspiration of material into lungs due to vomiting can cause chemical pneumonitis which can be fatal. Consult physician or poison control center immediately. Treat symptomatically.

Section VI—REACTIVITY DATA

STABILITY ☐ UNSTABLE ☒ STABLE CONDITIONS TO AVOID High temperatures

INCOMPATABILITY (Materials to avoid) Oxidizing materials

HAZARDOUS DECOMPOSITION PRODUCTS May produce hazardous fumes when heated to decomposition as in welding.

HAZARDOUS POLYMERIZATION ☐ MAY OCCUR ☒ WILL NOT OCCUR

Figure B1 (Cont'd).

Section VII—SPILL OR LEAK PROCEDURES 35-EF-51

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED Remove all sources of ignition (flame, hot surfaces, and electrical, static, or frictional sparks.) Avoid breathing vapors. Ventilate area. Contain and remove with inert absorbent and non-sparking tools.

WASTE DISPOSAL METHOD Dispose of in accordance with local, state, and federal regulations. Incinerate in approved facility. Do not incinerate closed containers.

Section VIII—SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION In outdoor or open areas use Bureau of Mines approved mechanical filter respirator to remove solid air borne particles of overspray during spray application. In restricted ventilation areas use Bureau of Mines approved chemical-mechanical filters designed to remove a combination of particulate and gas and vapor. In confined areas use Bureau of Mines approved air line type respirators or hoods.

VENTILATION All application areas should be ventilated in accordance to OSHA Regulation 29CFR 1910.94, 1910.107, 1910.108. Remove decomposition products formed during welding or flame cutting on surface coated with this product. If baking vent fumes.

PROTECTIVE GLOVES Recommended

EYE PROTECTION Safety eyewear including splash guards or side shields recommended

OTHER PROTECTIVE EQUIPMENT Use protective outerwear and prevent prolonged skin contact with contaminated clothing.

Section IX—SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Do not store above 120°F. Store large quantities only in buildings designed to comply with OSHA 1910.106. Keep closures tight and container upright to prevent leakage. Do not store or use near heat, sparks or flame. Never use pressure to empty. Drum must not be washed out or used for other purposes. Drums of this material should be grounded when pouring.

Do not get in eyes. Avoid skin contact. Can cause allergic respiratory reaction. Can cause allergic skin reaction. Prevent prolonged or repeated breathing of vapor or spray mist. Avoid breathing of sanding dust. Close container after each use. Do not handle until the manufacturers safety precautions have been read and understood. Keep out of reach of children.

Figure B1 (Cont'd).

MATERIAL SAFETY DATA SHEET

FOR COATINGS, RESINS AND RELATED MATERIALS

GSF

(Approved by U.S. Department of Labor "Essentially Similar" to Form OSHA-20)

Section I

MANUFACTURER'S NAME Mobile Paint Mfg. Co., Inc.   DATE OF PREP

STREET ADDRESS P. O. Box 717   CITY, STATE, AND ZIP CODE Theodore, AL. 36590

EMERGENCY TELEPHONE NO. (205) 653-0110   PRODUCT CLASS Epoxy Coating

INFORMATION TELEPHONE NO. (205) 653-0110

MANUFACTURER'S CODE IDENTIFICATION 40-AW-23   TRADE NAME MIL-P-24441/3A Whitc T/C Formula 152-Component A

Section II—HAZARDOUS INGREDIENTS

INGREDIENT	C.A.S. NO.	PERCENT BY WT.	TLV-TWA PPM	TLV-TWA Mg/M3	VAPOR PRESSURE
n-Butyl alcohol *This is a ceiling limit		30.8	50*	150*	6.5

Section III—PHYSICAL DATA

BOILING RANGE 240-247°F   VAPOR DENSITY X HEAVIER O LIGHTER THAN AIR

EVAPORATION RATE O FASTER OX SLOWER THAN ETHER   PERCENT VOLATILE BY VOLUME 54.5   WEIGHT PER GALLON 11.94

Section IV—FIRE AND EXPLOSION HAZARD DATA

FLAMMABILITY CLASSIFICATION OSHA - Combustible liquid Class 2   FLASH POINT °F 105°F (SETAFLASH)   LEL 1.4

EXTINGUISHING MEDIA

X FOAM   X ALCOHOL FOAM   X CO_2 X DRY CHEMICAL   O WATER FOG   O OTHER

UNUSUAL FIRE AND EXPLOSION HAZARDS During emergency conditions overexposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent. Obtain medical attention. Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions.

Full protective equipment including self-contained breathing apparatus should be used. Water spray may be ineffective. If water is used, fog nozzles are preferable. Water may be used to cool closed containers to prevent pressure build-up and possible autoignition or explosion when exposed to extreme heat.

Figure B1 (Cont'd).

Section V—HEALTH HAZARD DATA 40-AW-23

EFFECTS OF OVEREXPOSURE

Inhalation: Anesthetic. Excessive inhalation can cause irritation of the respiratory tract, or acute nervous system depression characterized by the following progressive steps: Headache, dizziness, staggering gait, confusion, unconsciousness, coma and even asphyxiation.

Skin Contact: Moderate irritation, defatting, dermatitis. May be a sensitizer in some individuals.

Eye Contact: Severe irritation, redness, tearing, blurred vision. May be a sensitizer in some individuals.

Ingestion: Gastrointestinal irritation, nausea, vomiting, and diarrhea.

EMERGENCY AND FIRST AID PROCEDURES Inhalation: Remove to fresh air. Administer oxygen if breathing is difficult. Restore breathing if necessary. Treat symptomatically. Consult a physician.

Splash (skin): Wash affected areas with soap and water. Remove and launder contaminated clothing. Consult a physician if irritation persists.

Splash (eyes): Flush immediately with large amounts of water for at least 15 minutes. Take to a physician for medical treatment.

Ingestion: Drink 1 or 2 glasses of water to dilute. Do not induce vomiting. Aspiration of material into lungs due to vomiting can cause chemical pneumonitis which can be fatal. Consult physician or poison control center immediately. Treat symptomatically.

Section VI—REACTIVITY DATA

STABILITY ☐ UNSTABLE ☒ STABLE CONDITIONS TO AVOID High temperatures

INCOMPATABILITY (Materials to avoid) Oxidizing materials

HAZARDOUS DECOMPOSITION PRODUCTS May produce hazardous fumes when heated to decomposition as in welding.

HAZARDOUS POLYMERIZATION ☐ MAY OCCUR ☒ WILL NOT OCCUR

Figure B1 (Cont'd).

Section VII— . . . OR LEAK PROCEDURES 40-AW-23

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED . . . all sources of ignition (flame, hot surfaces, and electrical . . . frictional sparks.) Avoid breathing vapors. Ventila . . . contain and remove with inert absorbent and non-sparking . . .

WASTE DISPOSAL METHOD Dispose of in acc rdance with local, state, and federal regulations. Incinerate in ap . . . facility. Do not incinerate closed containers.

Section VIII—SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION In outdoor or open areas use Bureau of Mines approved mechanical filter respirator to remove solid air borne particles of overspray during spray application. In restricted ventilation areas use Bureau of Mines approved chemical-mechanical filters designed to remove a combination of particulate and gas and vapor. In confined areas use Bureau of Mines approved air line type respirators or hoods.

VENTILATION All application areas should be ventilated in accordance to OSHA Regulation 29CFR 1910.94, 1910.107, 1910.108. Remove decomposition products formed during welding or flame cutting on surface coated with this product. If baking vent fumes.

PROTECTIVE GLOVES Recommended

EYE PROTECTION Safety eyewear including splash guards or side shields recommended

OTHER PROTECTIVE EQUIPMENT Use protective outer-wear and prevent prolonged skin contact with contaminated clothing.

Section IX—SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Do not store above 120°F. Store large quantities only in buildings designed to comply with OSHA 1910.106. Keep closures tight and container upright to prevent leakage. Do not store or use near heat, sparks or flame. Never use pressure to empty. Drum must not be washed out or used for other purposes. Drums of this material should be grounded when pouring.

Do not get in eyes. Avoid skin contact. Can cause allergic respiratory reaction. Can cause allergic skin reaction. Prevent prolonged or repeated breathing of vapor or spray mist. Avoid breathing of sanding dust. Close container after each use. Do not handle until the manufacturers safety precautions have been read and understood. Keep out of reach of children.

Figure B1 (Cont'd).

ESSENTIAL DATA

PRODUCT	Industrial McPoxY Coating 40-AH-42, 40-AW-23, 40-BH-5 with Catalyst 35-EF-51
TYPE VEHICLE	Epoxy/Polyamide
WEIGHT PER GALLON	Haze Gray 10.1-10.6 #-Dark Gray 10.0-10.3 #-White 10.3-11.3#
NON-VOLATILE % BY WT. NON-VOLATILE % BY VOL.	71.0% ± 1.0% 55.5% ± 0.5%
THEORETICAL SPREADING RATE FOR 1 MIL DRY FILM	890 Square Feet
SUGGESTED DRY FILM THICKNESS PER COAT	2-3 mils
SPREADING RATE — Loss must be considered due to texture, porosity, and structural shape of surface, weather conditions, and application equipment, use from 70% to 80% of theoretical coverage as figured from above.	
DRY TO TOUCH OR HANDLE (Normal Conditions) DRY TO RECOAT (Normal Conditions)	2 hours 8 hours
COLORS	Haze Gray, White, Dark Gray
THINNER	McPoxY Thinner 75-37 for cleanup
GLOSS OF DRY PAINT	White - Semi-Gloss Haze Gray and Dark Gray-Low Semi-Gloss
DRY FILM RESISTANT TO	Water, chemicals, abrasion
FLASH POINT OF L[illegible]D PAINT	100°F Mixed

FOR USE ON

TYPICAL SURFACE	Interior	Exterior	Undercoat Required
WOOD			
Siding	No	No	
Trim, Paneling, Doors	"	"	
Shingles, Shakes	"	"	
Floors, Porches, Steps	"	"	
METAL			
Steel, Iron (Ferrous)	Yes	Yes	40-CM-1 (MIL-P-24441/1A)
Galvanized Steel	"	"	40-CM-1 (MIL-P-24441/1A) & 9-42
Aluminum	"	"	40-CM-1 (MIL-P-24441/1A) & 9-42
MASONRY, PLASTER, ETC.			
Plaster	Yes	No	Self Prime
Concrete, Masonry	Yes	Yes	Self Prime
Brick	Yes	Yes	Self Prime
Asbestos Board & Shingles	Yes	Yes	Self Prime
Gypsum Board (Drywall)	Yes	No	Self Prime
Fiber Board (Masonite)	Yes	Yes	Self Prime
Open Textured Block	Yes	Yes	Fill & Self Prime
Floors, Porches, Steps	Yes	Yes	Self Prime

Figure B1 (Cont'd).

Amercoat® 99HS

Vinyl Chloride Copolymer

Ameron.

High solids, high build, sprayable vinyl topcoat

Economical—5 mils in a single coat

Resistant to a wide range of chemicals

All purpose maintenance coating for protection on primed steel, concrete, aluminum and galvanized surfaces

Conforms to U.S. Department of Agriculture requirements for use on steel in meat packing plants

A fast-drying coating which can be applied over inorganic zinc primers

Typical Uses
Protection against splash, spillage and fumes of corrosive chemicals, water, weathering and abrasion on primed steel, concrete, aluminum, galvanizing, Dimetcote® surfaces, chemical process plants, paper mills, marine structures and tank exteriors

Outstanding Characteristics
Amercoat 99HS is a high-performance chemical- and corrosion-resistant vinyl chloride copolymer. The cost is lower per square foot due to its high solids content and high build per coat necessitating fewer coats to achieve the desired thickness. It is resistant to a variety of chemical and weather environments and still retains its color and surface appearance.
Amercoat 99HS is a fast-drying, all-purpose maintenance coating which can be applied over inorganic as well as organic zinc primers

Application Data Summary
For complete information on procedures, equipment and safety precautions, see detailed Application Instructions.
Amercoat 99HS must be applied as recommended to obtain maximum performance.
Surface Preparation—Refer to Amercoat 99HS Application Instructions or primer to be used
Equipment—Use standard industrial spray equipment, either airless or conventional
Safety—Since improper use and handling of Amercoat 99HS can be hazardous to health and cause fire or explosion, safety precautions included with the Applications Instructions must be observed during all storage, handling, use and drying periods

Resistance Table

	Splash and Spillage	Atmospheric
Acids	Good	Excellent
Alkalis	Good	Excellent
Alcohols	Good	Good
Salts	Excellent	Excellent
Petroleum products	Good	Good
Food products	Good	N.A.

Note: Amercoat 99HS should not be exposed to ketones, esters or hydrocarbons of high aromatic content

Physical Data

Finish ....Flat
Color ....White; see color card for full range of industrial colors
Surface ....Primed steel
Components 1
Volume solids ....40% (ASTM D 2697)
Dry film thickness ....5 mils (125 μ) per coat

Allow for application loss and surface irregularities.

Coats ....1 (airless), 2 (conventional)
Calculated coverage at
  1 mil (25 μ) ....641 sq ft/gal (16 sq m/ltr)
  5 mils (125 μ) ....128 sq ft/gal (3.2 sq m/ltr)
Application ....Airless or conventional spray
Pot Life ................N.A.
Drying times
  @ 70°F (21°C) ....ASTM D1640
  Set to touch ....20 minutes
  Dry hard ....60 minutes
  Dry through ....2 hours
Drying time to recoat ....2 hours @ 70°F (21°C)
Temperature limit ....Up to 160°F (dry)
Flash point (Tag Closed Cup, ASTM D 56) ....60°F (16°C)
Thinner ....Amercoat 8 (above 70°F), Amercoat 10 (below 70°F)
Cleaner ....Amercoat 12
Packaging ....5-gal container
Shipping weight
  5-gal unit ....Approximately 57.5 lbs (26.0 kg)
Shelf life ....1 year from shipment date when stored indoors

Figure B2. Vendor information: Ameron system.

Amercoat® 99HS

Recommended Systems Using Amercoat 99HS

Substrate	Primer	No. of Coats for Amercoat 99HS
Dimetcote*		1-2
Steel	86, 62, 185, 160, 71	1-2
Concrete, aluminum galvanizing	86, 185	1-2

This chart and resistance table are only guides to show typical recommendations for Amercoat 99HS. In specific exposures and recommendations, please contact your Ameron representative who will help you evaluate your particular corrosion protection needs.

*When Amercoat 99HS is applied directly over inorganic zincs or zinc-rich primers a "mist coat" may be required to minimize application bubbling. See Application Instructions.

Warranty
Ameron's products are warranted to be free of defects in material or workmanship. If a product does not conform with this Warranty, Buyer must notify Ameron within five days of discovery of the defect, but in no event later than one year after delivery date or after expiration of the applicable shelf life, whichever is shorter. Ameron's sole obligation under this Warranty shall be at its option, to credit Buyer's account, or to supply replacement material or repair. Failure to notify Ameron of nonconforming goods under this Warranty, within the time specified above, shall bar Buyer from recovery hereunder.

It is expressly understood that Ameron makes no other warranties concerning the goods, and the sole remedy of the Buyer and the sole liability of Ameron for product defect shall be as set forth above. No other warranties, express or implied, whether of merchantability or of fitness for any particular use shall apply. Ameron shall not be responsible for consequential damages.

Any recommendation or suggestion relating to the use of the products made by Ameron either in technical literature or in response to specific inquiry is given in good faith, but it is for Buyer to satisfy itself of the suitability of the goods for its own particular purpose and it will be deemed to have done so.

Ameron
Protective Coatings Division

Figure B2 (Cont'd).

Application Instructions

Amercoat® 86

Synthetic resin inhibitive primer

Amercoat 86 is a synthetic resin inhibitive primer used as a maintenance or marine primer for a wide range of topcoats.

To obtain the maximum performance for which Amercoat 86 is formulated, strict adherence to all application instructions, precautions, conditions and limitations is necessary.

Surface Preparation

Steel

Nonimmersion—New steel without pits or depressions: blast in accordance with SSPC-SP6*, Commercial Blast. Previously painted or pitted steel: blast in accordance with SSPC-SP10*, Near White. For mild exposures: power tool cleaning in accordance with SSPC-SP3* is acceptable.

Immersion—Blast all steel in accordance with SSPC-SP10*, Near White as a minimum. Blast to achieve a 1 mil (25 μ) profile as determined with a Keane-Tator Surface Profile Comparator or similar instrument. Remove abrasive residue and dust from surface. Apply Amercoat 86 as soon as possible to prevent rusting or other recontamination.

Newly galvanized surfaces—Remove any oil or soap film with neutral detergent or emulsion cleaner. Use zinc treatment such as Galvaprep by Amchem Products, Ambler, PA.

Weathered galvanized surfaces—If galvanizing has been exposed to exterior weathering for 6 months or more, remove corrosion with hand or power sander. Remove any oil or grease.

Dimetcote®—Surface must be clean and dry. Remove any contamination including curing residue. If surface is glazed, roughen by sweep-blasting. Refer to application instructions for the particular Dimetcote for any other special topcoating requirements.

Aluminum surfaces—Remove oil, grease, etc. Apply chromate-type conversion treatment such as Alodine 1200 by Amchem Products, Ambler, PA, or lightly blast with fine sand.

Previously coated surfaces—All surfaces must be free of oil and grease. Spot blast to exposed metal or mechanically clean to remove rust or other contaminants. Before using Amercoat 86, test to see if solvents in Amercoat 86 will cause wrinkling, bleeding or lifting of coating.

Environmental Conditions

Air temperature—35 to 120°F (1.7 to 49°C)

Surface temperature—35 to 120°F (1.7 to 49°C)

The surface temperature must be at least 5°F (3°C) above the dew point to prevent moisture condensation.

Application Equipment

The following equipment is listed as a partial guide and suitable equipment from other manufacturers may be used. Adjustments of pressures and change of tip size may be needed to achieve the proper spray characteristics.

Airless spray—Standard airless spray equipment such as Graco Bulldog Hydra-Spray or larger with a 0.013-in. to 0.015-in. orifice.

Conventional spray—Industrial equipment such as DeVilbiss MBC or JGA spray gun. Separate regulators for air and fluid pressure, mechanical pot agitator and a moisture and oil trap in the main air supply line are recommended.

Power mixer—Mixer such as Jiffy Mixer, manufactured by the Jiffy Mixer Company, Inc., San Francisco, California, powered by an explosion-proof electric motor.

Application Procedure

1. Clean equipment with Amercoat 12 before use.
2. Stir material thoroughly with a power mixer until uniformly blended to a workable consistency.
3. Thin with up to 1 pint Amercoat 9 per gallon of Amercoat 86 for brush or roller, 1 quart Amercoat 9 per gallon of Amercoat 86 for spray. Use only Amercoat 9 for thinning.
4. Apply a heavy, wet coat in even, parallel passes overlapping each pass 50% to avoid holidays, bare areas or pinholes.
5. Double coat all welds, rough spots, sharp edges and corners, rivets, bolts, etc.
6. For concrete surfaces, thin first coat with equal parts of Amercoat 9 only. Apply by brush. Apply second coat by spray, brush or roller. Extremely rough, pitted or porous concrete may require additional coats.
7. Allow at least one hour at 70°F (21°C) before recoating or handling.
8. Clean all equipment with Amercoat 12 immediately after use.

Safety Precautions

Caution! Combustible. Contains MIBK, cyclohexanone and glycol ether ester. Irritating to skin, eyes and mucous membranes. Inhalation of high concentrations of vapors can cause headache, nausea or dizziness. Keep away from open flame, heat or sparks. Avoid breathing of vapor or skin and eye contact. Keep container closed when not in use. Use adequate ventilation. Wear approved respiratory equipment and skin and eye protection.

*Steel Structures Painting Council Specifications

Figure B2 (Cont'd).

First aid—Excessive exposure to vapor, provide fresh air. Give artificial respiration if breathing is labored. For skin contact, wash thoroughly with soap and water. For eyes, flush immediately with plenty of water for at least 15 minutes and get medical attention. Launder contaminated clothing before reuse.

In case of fire—blanket flames with dry chemical, carbon dioxide or foam. Wear self-contained breathing apparatus.

In case of spillage—eliminate all sources of ignition. Absorb and dispose of in accordance with all applicable regulations.

Improper use and handling of this product can be hazardous to health and cause fire or explosion. Consult Code of Federal Regulations Title 29, Labor, parts 1910 and 1916 concerning occupational safety and health standards and regulations, as well as any applicable state and local regulations on safe practices in coating operations. Necessary safety equipment must be used and ventilation requirements carefully observed, especially in confined or enclosed spaces.

If you do not fully understand these warnings and instructions, or if you cannot strictly comply with them, do not use the product.

Notice—This product is for industrial use only.

Warranty

Ameron's products are warranted to be free of defects in material or workmanship. If a product does not conform with this Warranty, Buyer must notify Ameron within five days of discovery of the defect, but in no event later than one year after delivery date or after expiration of the applicable shelf life, whichever is shorter. Ameron's sole obligation under this Warranty shall be at its option, to credit Buyer's account, or to supply replacement material or repair. Failure to notify Ameron of nonconforming goods under this Warranty, within the time specified above, shall bar Buyer from recovery hereunder.

It is expressly understood that Ameron makes no other warranties concerning the goods, and the sole remedy of the Buyer and the sole liability of Ameron for product defect shall be as set forth above. No other warranties, express or implied, whether of merchantability or of fitness for any particular use shall apply. Ameron shall not be responsible for consequential damages.

Any recommendation or suggestion relating to the use of the products made by Ameron either in technical literature or in response to specific inquiry is given in good faith, but it is for Buyer to satisfy itself of the suitability of the goods for its own particular purpose and it will be deemed to have done so.

201 North Berry Street
Brea, California 92621

Ameron.

Protective Coatings Division

Figure B2 (Cont'd).

Safety Precautions

To protect personnel against toxic hazards

To prevent fire or explosion

Whenever coatings containing volatile solvents or toxic substances are used, proper ventilation and protective measures must be provided during application and drying to keep solvent vapor concentrations within safe limits and to protect personnel against toxic hazards. This is especially true in confined spaces such as tank interiors. Consult Code of Federal Regulations Title 29, Labor, parts 1910 and 1916 concerning occupational safety and health standards and regulations, as well as any applicable state and local regulations on safe practices in coating operations. Necessary safety equipment must be used and ventilation requirements carefully observed, especially in confined or enclosed spaces.

Keep solvent-containing materials away from heat, sparks, and open flame. Avoid inhalation of vapors or spray mist. Avoid contact with eyes or skin. Keep containers tightly closed and upright to prevent leakage when not in use.

Refer to application instructions for the material being applied for further detailed safety precautions. Department of Labor Material Safety Data Sheets are available on request.

If you do not fully understand these warnings and instructions, or if you cannot strictly comply with them, do not use the product.

Notice — This product is for industrial use only.

201 North Berry Street
Brea, California 92621
(714) 529-1951

Ameron
Protective Coatings Division

SG-2

Figure B2. (Cont'd).

MATERIAL SAFETY DATA SHEET

NPCA 1-

FOR COATINGS, RESINS AND RELATED MATERIALS

(Approved by U.S. Department of Labor "Essentially Similar" to Form OSHA-20)

DATE OF PREP 5-13-81

Section I

1071-148

PLAS-CHEM COATINGS

P.O. Box 40246, Jacksonville, FL 32203
(904) 786-0121

EAGLE-PICHER INDUSTRIES

5901 W. Beaver Street zip 32205
(904) 7860121

PRODUCT CLASS

2 Component Epoxy

TRADE NAME

MANUFACTURERS CODE IDENTIFICATION

2135-1 White Finish

MIXED

Section II — HAZARDOUS INGREDIENTS

INGREDIENT	PERCENT	TLV skin PPM	TLV mg/m³	LEL	VAPOR PRESSURE @ 20° C
2-Ethoxy Ethanol	less than 5	100	370	1.0	5.3 @ 25° C
SC-100	30	100	---	1.0	<1
N-Butyl Alcohol	less than 5	50	150	1.2 @ 25° C	4.39
N.-Butyl Acetate	less than 5	150	710	1.7	7.8

Section III — PHYSICAL DATA

BOILING RANGE 243-262° F

VAPOR DENSITY [X] HEAVIER [ ] LIGHTER THAN AIR

EVAPORATION RATE [ ] FASTER [X] SLOWER THAN ETHER

PERCENT VOLATILE BY VOLUME 52

WEIGHT PER GALLON 10.2 ± .15

Section IV — FIRE AND EXPLOSION HAZARD DATA

DOT CATEGORY

Flammable Liquid-Class 1 C

FLASH POINT 76° F TCC

LEL 1.0

EXTINGUISHING MEDIA

Chemical Extinguishers, Foam, Sand, CO_2

UNUSUAL FIRE AND EXPLOSION HAZARDS

None

SPECIAL FIRE FIGHTING PROCEDURES

Prevent spread of fire by cooling adjacent containers with water fogging or removal if possible.

Figure B3 (Cont'd).

Section V — HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE

EFFECTS OF OVEREXPOSURE

Inhalation: Dizziness, headache
Skin Contact: Redness, rash

EMERGENCY AND FIRST AID PROCEDURES

Inhalation: Fresh air
Skin contact: Wash with soap and water; apply hand cream
Eye contact: Rinse with large amounts of water

Section VI — REACTIVITY DATA

STABILITY [ ] UNSTABLE [XX] STABLE CONDITIONS TO AVOID

INCOMPATABILITY (Materials to avoid)

HAZARDOUS DECOMPOSITION PRODUCTS

Carbon monoxide and carbon dioxide

HAZARDOUS POLYMERIZATION [ ] MAY OCCUR [XX] WILL NOT OCCUR

CONDITIONS TO AVOID

Section VII — SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Scoop up in container - Rinse with water

WASTE DISPOSAL METHOD

Burying or incineration in accordance with local, state, and federal regulations

Section VIII — SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION

Not normally necessary when working with small amounts. For large spray applications, BU Mines filter respirator for organic solvents is advisable.

VENTILATION

Exhaust ventilation from enclosed areas recommended

PROTECTIVE GLOVES protective hand cream

EYE PROTECTION goggles

OTHER PROTECTIVE EQUIPMENT

Section IX — SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

Do not st[illegible] in direct sun. Keep protected from exposure to heat.

OTHER PRECAUTIONS

Do not use in c[illegible] proximity to heat and open flame welding and other ignition hazards.

Figure B3 (Cont'd).

MATERIAL SAFETY DATA SHEET

NPCA 1-

FOR COATINGS, RESINS AND RELATED MATERIALS

(Approved by U.S. Department of Labor "Essentially Similar" to Form OSHA-20)

DATE OF PREP 5-13-81

Section I

1071-246

PLAS-CHEM COATINGS P.O. Box 40246, Jacksonville, FL 32203 (904) 786-0121

EAGLE-PICHER INDUSTRIES 5901 W. Beaver Street zip 32205 (904) 7860121

PRODUCT CLASS 2 Component Epoxy

TRADE NAME

MANUFACTURERS CODE IDENTIFICATION 2135-1 White Finish

Section II — HAZARDOUS INGREDIENTS

MIXED

INGREDIENT	PERCENT	TLV skin PPM	TLV mg/m³	LEL	VAPOR PRESSURE @ 20° C
2-Ethoxy Ethanol	less than 5	100	370	1.0	5.3 @ 25° C
SC-100	30	100	---	1.0	<1
N-Butyl Alcohol	less than 5	50	150	1.2 @ 25° C	4.39
N.-Butyl Acetate	less than 5	150	710	1.7	7.8

Section III — PHYSICAL DATA

BOILING RANGE 243-262° F

VAPOR DENSITY [X] HEAVIER [ ] LIGHTER THAN AIR

EVAPORATION RATE [ ] FASTER [X] SLOWER THAN ETHER

PERCENT VOLATILE BY VOLUME 52

WEIGHT PER GALLON 10.2 ± .15

Section IV — FIRE AND EXPLOSION HAZARD DATA

DOT CATEGORY Flammable Liquid-Class 1 C

FLASH POINT 76° F TCC

LEL 1.0

EXTINGUISHING MEDIA

Chemical Extinguishers, Foam, Sand, CO_2

UNUSUAL FIRE AND EXPLOSION HAZARDS

None

SPECIAL FIRE FIGHTING PROCEDURES

Prevent spread of fire by cooling adjacent containers with water fogging or removal if possible.

Figure B3 (Cont'd).

Section V — HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE See Section II

EFFECTS OF OVEREXPOSURE

Inhalation: Dizziness, nausea, headache
Ingestion:
Skin contact: Eczema, rash

EMERGENCY AND FIRST AID PROCEDURES

Eye contact: Flood with stream of water
Inhalation : Fresh Air
Ingestion : Call Physician for advice. DO NOT induce vomiting
Skin contact Wash off with solvent, followed by soap and water
Apply skin cream

Section VI — REACTIVITY DATA

STABILITY ☐ UNSTABLE ☒ STABLE At normal conditions

CONDITIONS TO AVOID Extreme heat

INCOMPATIBILITY (Materials to avoid)

HAZARDOUS DECOMPOSITION PRODUCTS

Carbon Mono and Dioxide.

HAZARDOUS POLYMERIZATION ☐ MAY OCCUR ☒ WILL NOT OCCUR

CONDITIONS TO AVOID

Section VII — SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED Scoop up in container using non-sparking tools. Soak remainder up with sand. Keep waste in closed container for disposal. Clean with suitable solve under proper ventilation.

WASTE DISPOSAL METHOD Dispose of waste by burying or incineration in accordance with local, state and federal regulations.

Section VIII — SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION

Bu Mines approved filter respirator for organic solvents.

VENTILATION Suction ventilation from lower reaches of enclosed areas.

PROTECTIVE GLOVES Protective skin cream recommended.

EYE PROTECTION Goggles

OTHER PROTECTIVE EQUIPMENT

Section IX — SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Store in well ventilated area protected from undue exposure to heat, sun and freezing.

OTHER PRECAUTIONS

Use explosion proof lights abd motors in work areas. Avoid welding and other ignition hazards in vicinity of use or handling.

Figure B3 (Cont'd).

Plas-Chem Coatings
TECHNICAL BULLETIN

Chem-Pon 2135
Epoxy Lining System

6-15-80

GENERAL DESCRIPTION

The Chem-Pon 2135 coating system consists of one primer and one finish. It is a unique, modified epoxy-polyamide that combines a rapid cure with unusually long pot life. This system is specifically designed to resist all types of aviation fuels, water and aliphatic solvents in immersion service. It also has good resistance to many herbicides, fungicides, pesticides and fumigants. Chem-Pon 2135 has outstanding adhesion, impact resistance and resistance to steam. It complies with MILC-4556C and is on the qualified product listing for aviation fuels.

USE

As a lining system over sandblasted metal to line tanks, for jet and aviation fuels, gasoline, aliphatic hydrocarbons, water and salt water subject to temperatures up to 140° F. It may also be used as a lining material for certain herbicides, fungicides at various concentrations. Chem-Pon 2135 may be used for external and splash zone use in the same application as well as splash zone protection for alkali or acid environments.

PHYSICAL PROPERTIES

Chemical Resistance:	Acids - Good Alkalis - Very Good Water - Excellent Solvents - (Aliphatic) Excellent Salts - Excellent Herbicides - Very Good * Pesticides - Very Good *
Temperature Resistance:	200° F. Continuously; 230° F. Intermittently
Flexibility:	Good
Weathering:	Very Good (Moderate Chalking)
Abrasion Resistance:	Excellent
Solids(Catalyzed 4:1 by volume):	Primer - 68%±1 by weight, 50%± 1 by volume Finish - 62%±1 by weight, 50%±1 by volume
Theoretical Coverage:	802 mil square feet per gallon
Recommended Coverage:	Minimum 3 mils per coat (Fuel Service) Standard 5 mils per coat
Number of Coats:	1 each of primer and finish
Surface Preparation:	SSPC-SP5-63 for immersion lining applications

Plas-Chem Coatings • 7001 West Beaver Street • Jacksonville, Florida 32205
Mailing Address: P.O. Box 40246 • Jacksonville, Florida 32203 • Telephone (904) 786-0121

Figure B3 (Cont'd).

PHYSICAL PROPERTIES(cont'd)

Colors:	Primer - Orange Finish - Off White
Flash Point:	$95 \pm 5^{\circ}$ F. Pinsky Martin $115 \pm 5^{\circ}$ F. COC

APPLICATION

Method:	Spray, brush or roller
Pot Life:	Minimum of 8 hours
Mixing Ratio:	4 parts of base to 1 part of catalyst by volume
Dry Time:	18 hours @ 75° F. between coats Final - 36 hours @ 75° F.
Thinner:	Standard: No. 146 Thinner Military Thinner: Chem-Pon 2136 Thinner
Clean Up:	MEK or any of the above thinners

ORDERING INFORMATION

Availability:	1¼ gal. kits (1 gal base and ¼ gal catalyst) 5 gal kits (4 gal base and 1 gal catalyst)
Approximate shipping weight:	Primer Base 12.5 lbs. per gal. Finish Base 11.7 lbs. per gal. Catalyst 2.5 lbs. per quart
Freight Classification:	Paint compound NOIBN Non-Red Label

*Due to many types and variations of these materials, contact Plas-Chem Coatings, Technical Services Dept. for specific recommendations before using in immersion service.

Figure B3 (Cont'd).

Plas-Chem Coatings

APPLICATION INSTRUCTIONS

CHEM-PON 2135
MEETS MIL-C-4556 C
FOR JET FUEL SERVICE

2-1-83

SURFACE PREPARATION

1. Immersion Service

   a. Sandblast to white metal in accordance with Steel Structures Painting Council Blast Specification (SSPS) SP5-63T. Mil profile shall be a minimum of 1.5 - 2 mils.

   b. Remove all loose dirt and abrasive media by vacuuming or sweeping.

   c. Apply prime coat of material as soon as possible after blasting to prevent re-rusting.

   d. If re-rusting has occurred, surface should be reblasted.

2. Non-Immersion Service

   a. Sandblast in accordance with SSPC SP6-63 Commercial Blast.

   b. Remove blasting dust by blowing surface with clean dry air free of oil and moisture.

   c. Paint surfaces before re-rusting occurs.

MIXING

1. Mix materials (base and catalyst) as supplied in kit form. Mixing ratio is 4 parts base to 1 part of catalyst by volume.

2. After mixing base and catalyst, allow 1/2 hour induction time before applying.

POT LIFE: Less than 15 % viscosity increase in 6 hours at 75° F.

THINNING: None normally required. However, if circumstances should dictate, use only a thinner and amounts listed below.

   a. Military Specification: Use only Chem-Pon 2135 M.S.T. Thinner up to 1/2 pint per gallon of mixed material.

   b. Non-Military Specification: Use Plas-Chem No. 146 Thinner up to 1/2 pint per gallon of mixed material.

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Mailing Address: P.O. Box 40246 • Jacksonville, Florida 32203 • Telephone (904) 786-0121

Figure B3 (Cont'd).

APPLICATION

AIRLESS	CONVENTIONAL AIR
Pump: 30:1 or larger	Pressure pot or 2:1 fluid pump
Oriface: .013-.029 depending on volume requirements	Guns: Binks 7, 18, 19, 62 DeVilbiss JGA, MBC or PMBC
Angle: 40 - 60 depending on surface requirements. Work close to surface to minimize drift and drop out.	Fluid Tip: .041-.070
	Air Cap: 7-13 CFM
	Hose: 3/8" ID Fluid Hose
Hose: 5/16" STD High Pressure Fluid	Pos Pressure: 5-20 PSI depending on hose length.
Pressure: 2600-3000 PSI	Atomizing Pressure: 45-65 PSI
Thinning: None normally required	Thinning: None normally required

Brushing or rolling is not recommended for immersion applications and should be used for touch up work only. Use High Quality natural bristle brush of medium length. Apply by flowing long strokes. Avoid re-brushing. Rolling - Use lambswool or mohair phenolic core roller of appropriate knapp length. Roll in one direction. Avoid "scrubbing" of surface.

THEORETICAL COVERAGE: 800 mil square feet per gallon.

INTER-COAT TIME: 18 hours at 75° F (Military Specification).
12 hours at 90° F

CURING: If possible, due to the slow solvent system used, it is advisable to force high volumes of slightly warm air at 75°-85° F for two hours through enclosed tanks. Increase temperature to 115°-125° F for 8 - 10 hours.

CURE TIME: 3 days at 75° F
For shorter time see "CURING".

CLEAN-UP: Plas-Chem No. 146 Thinner, MIL Spec Thinner, or MEK.

CAUTION:

1. Contains flammable solvent.
2. Keep away from open flame and sparks. Use only approved explosion proof equipment. In tank lining applications workmen must wear Air Respirators provided with a source of fresh air.
3. Remove any spilled catalyst from hands or skin at once with water, then wash with soap and water.
4. If catalyst is spilled on clothing, remove clothing at once, wash skin as above.
5. Mix and apply Chem-Pon 2310 in a well ventilated area. Keep away from sparks and open flame. In tank lining applications, workmen must wear air respirators equipped with a source of fresh air.
6. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NON-FERROUS TOOLS AND WEAR CONDUCTIVE AND NON-SPARKING SHOES.

Figure B3 (Cont'd).

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